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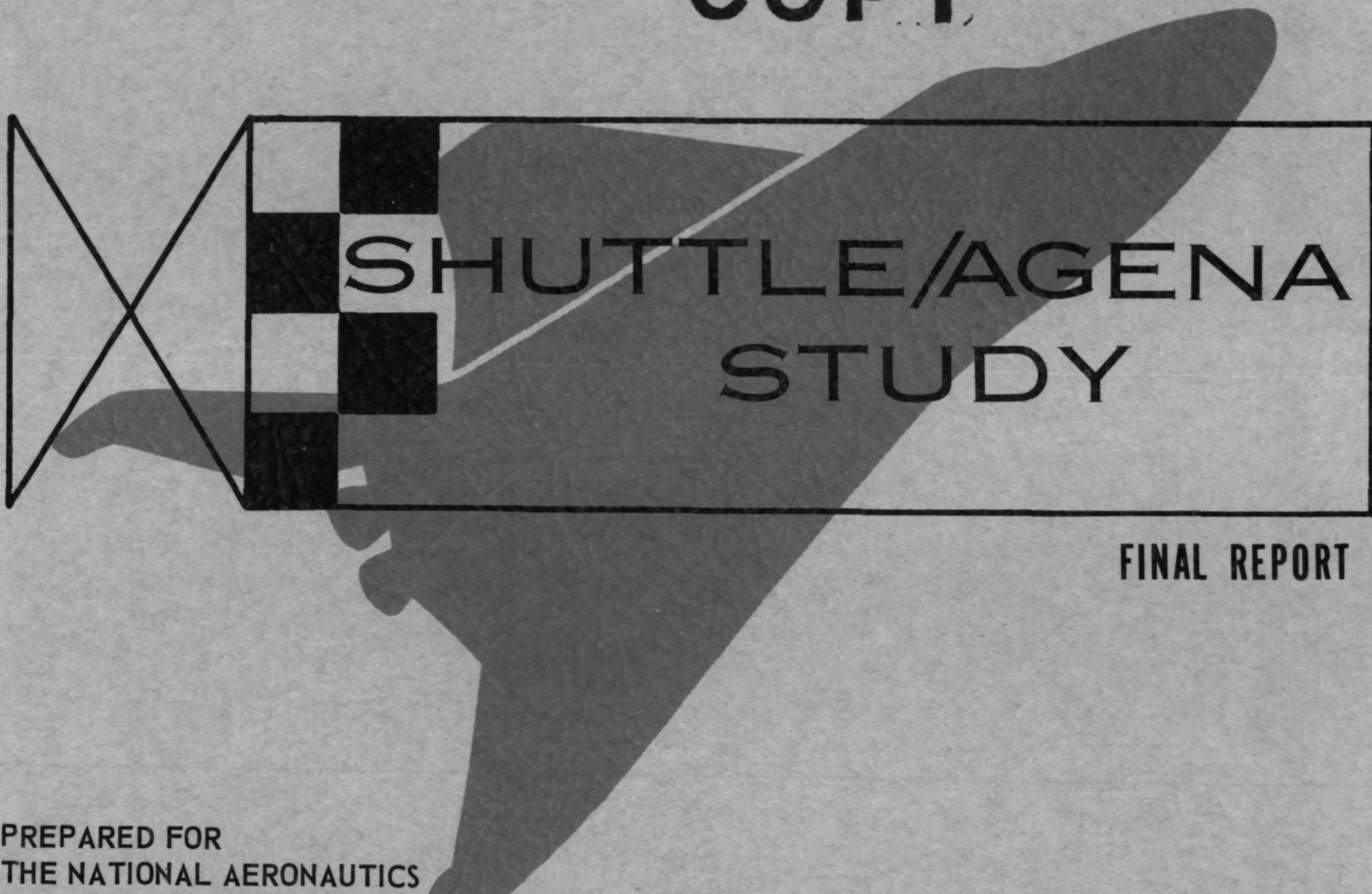

SHUTTLE/AGENA STUDY

FINAL REPORT

PREPARED FOR
THE NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER • HOUSTON, TEXAS

CONTRACT NAS9-11949

LMSC
SPACE SYSTEMS
DIVISION

VOLUME II
TECHNICAL REPORT
PART TWO:
AGENA TUG CONFIGURATIONS, SHUTTLE/AGENA INTERFACE, PERFORMANCE, SAFETY, COST

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

25 February 1972

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Prepared for the

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Manned Spacecraft Center

Houston, Texas

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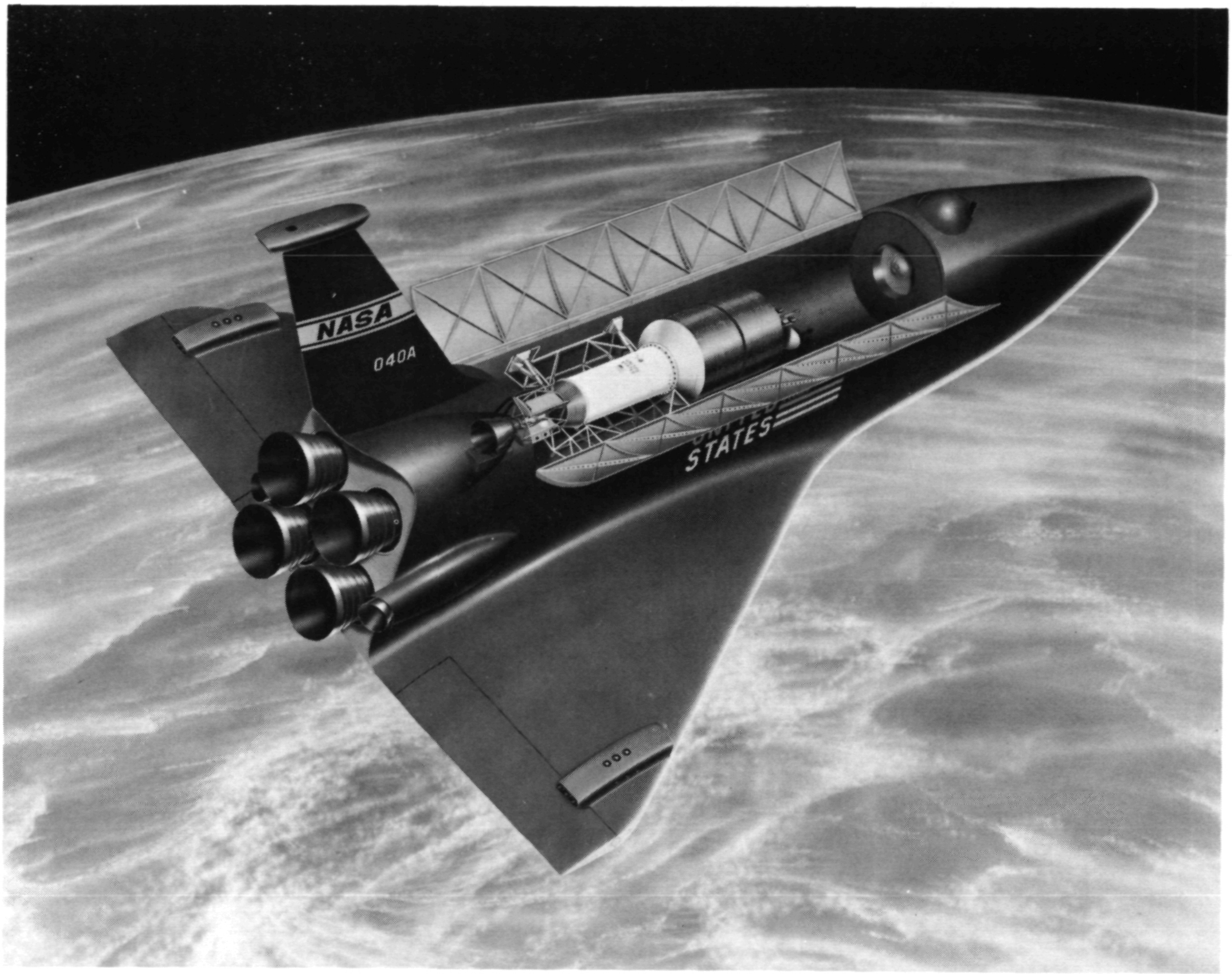
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FOREWORD

This final report has been prepared for the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas, under Contract NAS9-11949. Volumes I and II are submitted as DRL line items 6 and 7, as specified in DRD MA-012T and MA-129T of the subject contract. Although not contractually required, supplemental data on the Ascent Agena and existing flight equipment are also submitted.

In compliance with customer guidelines regarding page limitations, the report is bound in separate books as follows:

• Volume I	Executive Summary
• Volume II, Part One	Program Requirements, Conclusions, Recommendations
• Volume II, Part Two	Agena Tug Configurations, Shuttle/Agena Interface, Performance, Safety, Cost
• Volume II, Part Three	Preliminary Test Plans
• Annex A	Ascent Agena Configuration
• Annex B	Catalog of Existing Flight Equipment
• Annex C	Space Shuttle Candidate Insulator/ Propellant Compatibility Test Program

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CONTENTS

ILLUSTRATIONS

TABLES

Section 1
INTRODUCTION

Section 1
INTRODUCTION

This book, Volume II, Part 2 of the final report, documents the major portion of the technical work completed during the Shuttle/Agena Compatibility study. The Agena space tug configuration design is described in terms of the total vehicle system as well as the individual subsystems and major assemblies and components. The complete interface between the Agena space tug and the space shuttle orbiter is defined in detail for both in-flight and ground operations.

The derivation and design of an evolutionary stage is also presented. This vehicle conforms to the same guidelines and interface requirements as the Agena space tug. Key safety problems are identified and promising solutions are presented.

Performance data developed for both vehicles for each of the three study baseline missions are included. Also presented are cost data, which were prepared to work breakdown structure Levels 6 and 7. These costs were then compared to historical Gemini Agena Target Vehicle costs to confirm their validity.

Section 2

AGENA TUG BASELINE CONFIGURATION DEFINITION

Section 2
AGENA TUG BASELINE CONFIGURATION DEFINITION

2.1 BASELINE CONFIGURATION

The Agena tug configuration consists of the Ascent Agena vehicle configuration as described in Annex A, with the subsystems modified as discussed under Section 5, Volume II, Part 1, to comply with the shuttle integration and to satisfy the mission requirements.

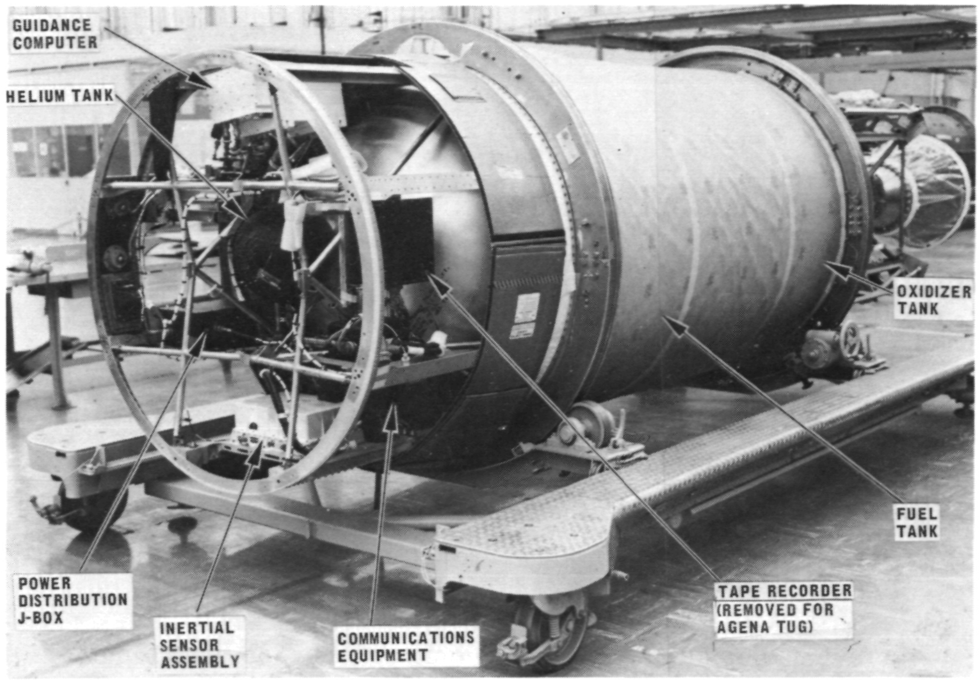
Actually, very few changes are required to convert the Ascent Agena vehicle into the Agena tug configuration. As discussed previously under Part 1, Section 5, most of the changes consist of internal substitution of subsystem components with corresponding modifications to the wiring and plumbing systems. The external appearance of the vehicle configuration will therefore be very similar to that of the Ascent Agena (Fig. 2-1.) An artist's conception of the Agena tug on orbit with two typical synchronous equatorial-orbit payloads is shown in Fig. 2-2.

The only significant change to the basic structure is the addition of two strengthening rings, one at Station 384 and one at the payload interface plane at Station 244. These two rings are indicated on the inboard profile drawing of the Agena tug configuration shown in Fig. 2-3.

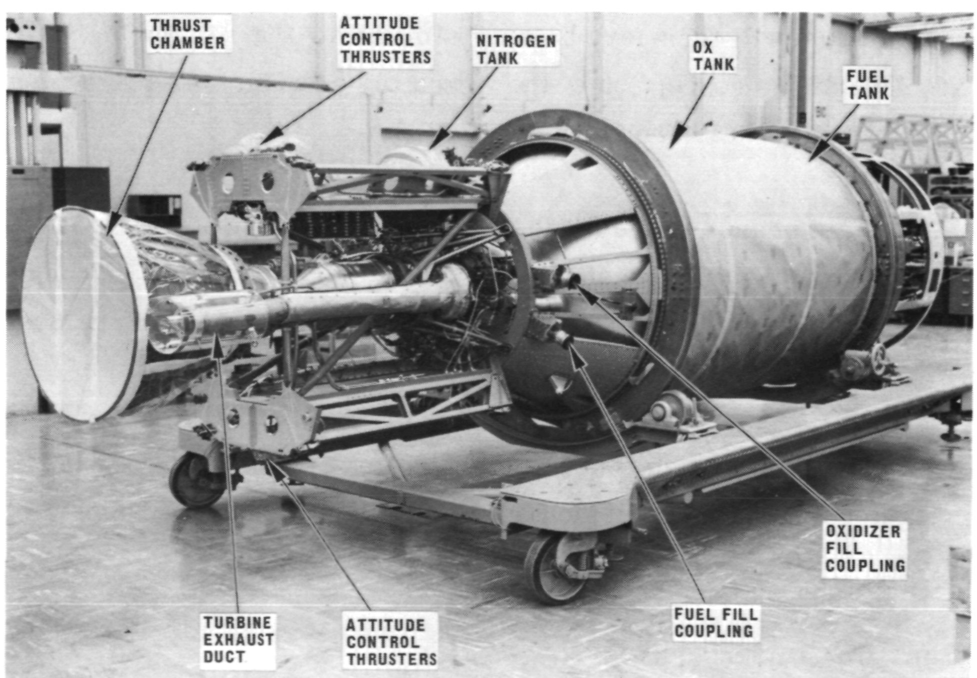
The modifications to the Ascent Agena configuration are summarized in the following paragraph; a more detailed discussion of the subsystems and the support equipment is included in Section 3.

2.2 REQUIRED MODIFICATIONS TO ASCENT AGENA

The required modifications to the Ascent Agena as outlined in Section 5, Volume II, Part 1 are outlined in Table 2-1. The modifications are organized both by subsystem



Forward View



Aft View

Fig. 2-1 Ascent Agena

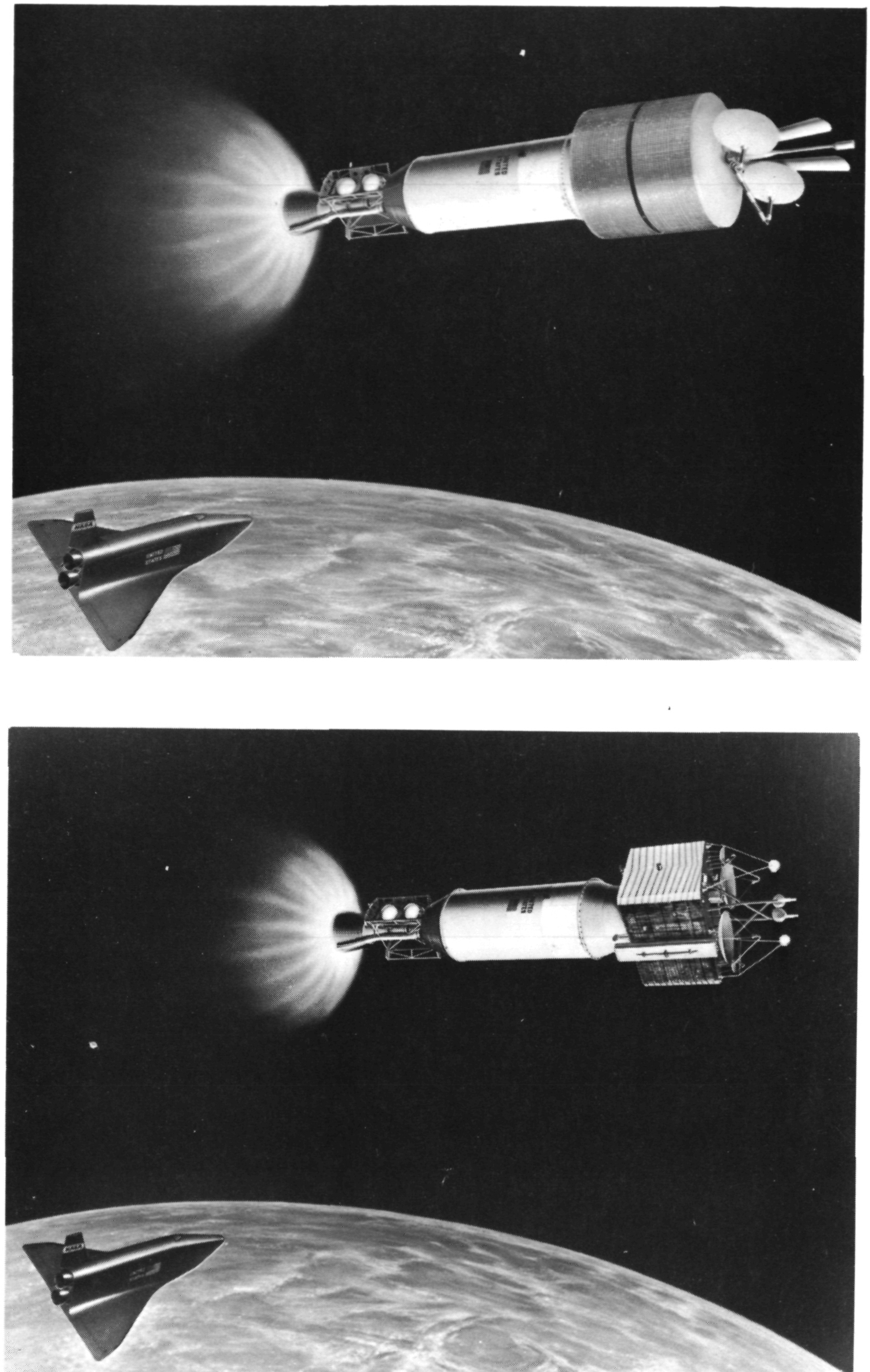


Fig. 2-2 Agena Tug on Orbit With Intelsat IV (Top) and Lockheed Communications Satellite (Bottom) Payloads

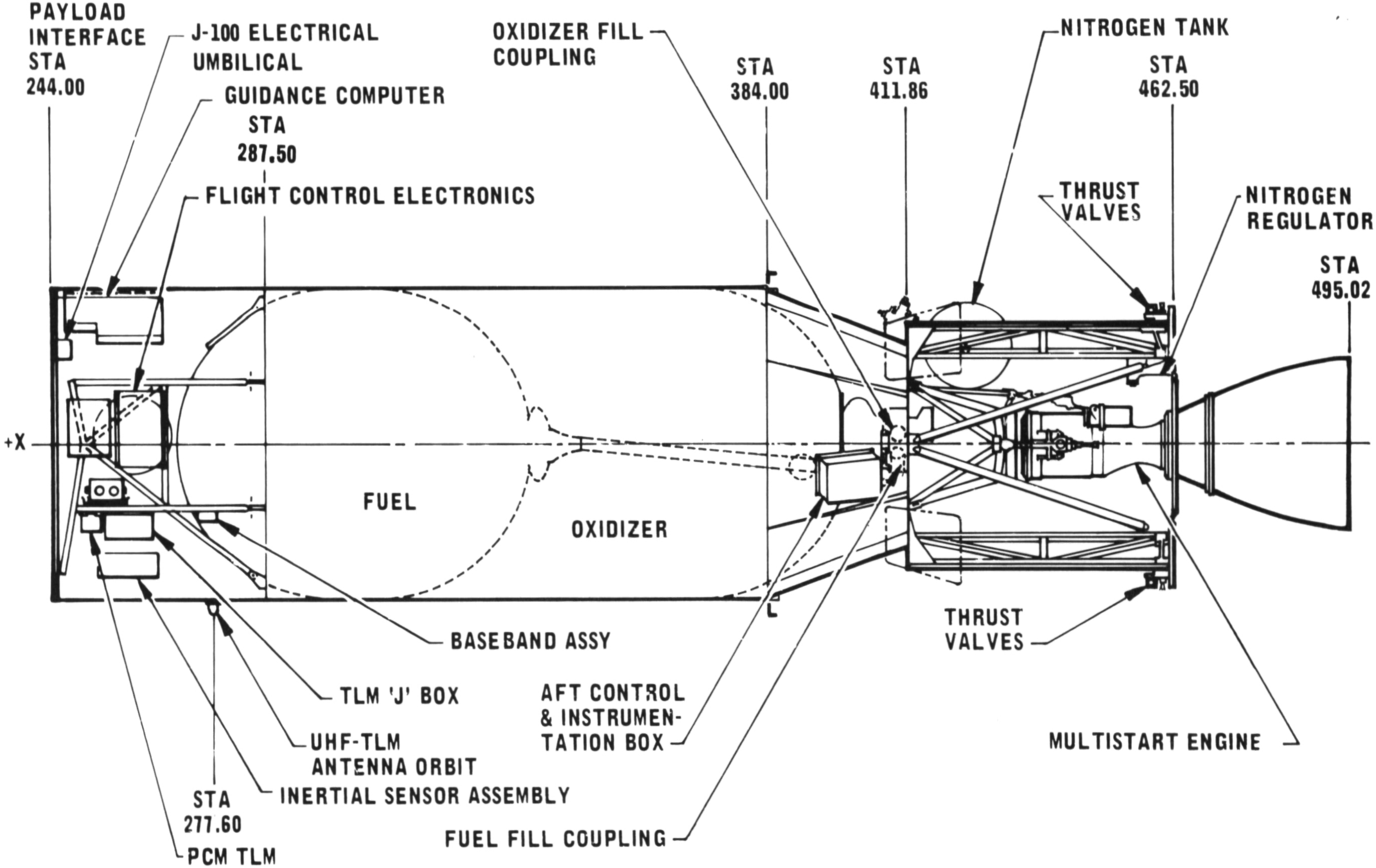


Fig. 2-3 Agena Space Tug Inboard Profile

Table 2-1

SUMMARY OF AGENA MODIFICATIONS

Modification	Reason for Change*	Planetary Injection	Sync-Eq Injection	30-Day Mission
Structures				
Tank Section				
Add attachment ring	SI	X	X	X
Add brackets for standard deployment mechanism	SI	X	X	X
Aft Rack				
Remove roller mechanisms	SI	X	X	X
If new nozzle, relocate structural members as required	MR	(TBD)	(TBD)	(TBD)
Add bracketry for additional equipment as required	MR	X	X	X
Propulsion				
Performance				
HDA, -1 injector, higher expansion nozzle	MR	(TBD)	(TBD)	(TBD)
Multistart capability	MR			X
Add relubrication kit	MR			X
Propellant storability				
Modify PIVs, seals	MR			X
Propellant dump capability				
Expand dump valves and plumbing	SI	X	X	X
Modify propellant vent system	SI	X	X	X
Modify pressurization system	SI	X	X	X
Communications				
Remove C-band beacon and ascent antenna	SI	X	X	X
Remove present communication equip.	SI	X	X	X
Add new communication units	SI	X	X	X
Guidance				
Ascent Guidance System				
Remove booster discrete box	SI	X	X	X
Add shuttle interface hardline	SI	X	X	X
Add safety and checkout sensors	SI	X	X	X
Add RF update capability	MR		(TBD)	X
Add DACS (or 1/2 DACS)	MR			

Table 2-1 (Cont)

Modification	Reason for Change*	Planetary Injection	Sync-Eq Injection	30-Day Mission
Electrical				
Remove destruct system	SI	X	X	X
Remove ascent tracking equipment	SI	X	X	X
Remove booster interface equipment	SI	X	X	X
Remove fairing separation equipment	SI	X	X	X
Change engine start system	MR			X
Add wiring for additional guidance equip.	MR			X
Add solar panels	MR			X
Change wiring for new communication equipment	SI	X	X	X

*SI – Shuttle Integration
MR – Mission Requirement

and by mission to emphasize the impact of mission requirements upon the Agena tug configuration. Most of the modifications are common to all missions; they result from integration with the shuttle system. The exceptions are the peculiar equipment needed for the long-duration mission. From a scheduling point of view, it would be advantageous to have one Agena tug configuration that could be used for all missions. This will, however, imply an increased configuration weight, which will penalize the performance capability for some of the applications. The following approach is therefore recommended:

- The multistart capability represents only a 29-lb increase in propulsion system weight. It is recommended that this capability be included in the standard configuration, in order to have only one engine model and thereby reduce cost and simplify vehicle scheduling.

- The RF update capability of the guidance system represents only a 2.3-lb weight increase. This added capability may also prove to be desirable for other missions and should therefore be included in the standard configuration.
- Solar panels for power supply for the long-duration mission can easily be installed outside the basic configuration. Provision for wiring and plug-in connection should be included in the standard configuration.
- Two baseline configurations are considered:

  One, using the standard Agena propulsion system with the addition of the multistart capability, will have a specific impulse of 290.8 sec.

  The other version will include a higher expansion nozzle, the HDA oxidizer, and a modified injector. This configuration, which is referred to as the "Improved baseline configuration," will have a specific impulse of 310 sec.

2.3 WEIGHT ESTIMATE

The weight estimates of the Agena tug vehicle configurations and the associated support equipment needed in the orbiter are summarized here. Table 2-2 gives the weight breakdown by vehicle subsystem of the Ascent Agena configuration as defined in Annex A, since this configuration was used as a starting point. Table 2-3 summarizes the weight summary of all the additional equipment and the modifications to the Ascent Agena configuration in order to arrive at the Agena tug configuration as previously defined in Table 2-1. A weight was determined for each of the three model missions. For the two short-duration missions the basic configuration is the same; the difference consists of additional batteries which will be installed at the launch pad. For the long-duration mission the increased weight consist of electrical supply equipment and additional control components. Table 2-4 gives the additional vehicle weights to incorporate the changes to the improved baseline configuration. In this case the weight of the propellant loaded is different, due to the use of the high-density acid (HDA) as oxidizer.

Table 2-5 summarizes the weight of the support items to be included in the orbiter. These items are nondeployable support equipment, which will remain with the orbiter when the Agena and the payload are deployed. The support item weight therefore does not affect the Agena payload capability, except when the maximum shuttle capability is reached. These support items are defined in Section 3. The Agena deployment system using the four bi-stem booms, as discussed under Section 3, is not included in the support system weight. This system, which is estimated to weigh approximately 300 pounds, must also be charged to the Agena system if it is used.

Finally, Table 2-6 gives weight sequences for the three model missions, from the total Agena weight and until the mission is completed. This table includes both the standard and the improved version of the baseline Agena configuration. The support equipment weight was obtained from Table 2-5, using a cradle compatible with the payload capability. The nonimpulse propellant was estimated on the basis of the required number of burning periods for each mission.

Table 2-2

WEIGHT BREAKDOWN FOR ASCENT AGENA

	Code	Weight (lb)
STRUCTURE		
Forward Section	A001	134.3
Tank Section	B001	275.9
Aft Section	C001	104.1
Contingency		5.1
Total		519.4
ELECTRICAL POWER		
Primary Batteries	K002	32.2
Power Distribution J-Box	A012	9.1
Aft Control and Instr J-Box	C012	6.2
Main Power Transfer Switch	C013	2.6
Wiring Harnesses	C022	11.1
Wiring Harnesses	B002	4.4
Wiring Harnesses	B011	0.2
Wiring Harnesses	A042	21.7
Pyrotechnic Control Box	A032	4.5
Contingency		0.9
Total		92.9
PROPULSION		
Rocket Engine	C003	225.5
Nozzle Extension Kit	K003	46.0
Dual Start Kit	C093	7.8
	K013	1.9

Table 2-2 (Continued)

	Code	Weight (lb)
PROPULSION		
Starter Grain Kit (2)	K033	2.6
Starter Igniter (2)	K023	1.2
Propellant Fuel Feed Bellows	C023	1.0
Propellant Oxygen Feed Bellows	C023	1.0
Helium Fill Coupling	A023	0.3
Pyro Helium Control Valve	A003	3.8
M-69 Pressure Squib	K010	0.1
M-11 Pressure Squib		
Fast Shutdown Kit		1.9
Propellant Vent Coupling	A043	0.4
High-Pressure Helium Coupling		–
Helium Tank	A013	15.9
Check Valve	C004	0.2
Fuel and Oxygen Feed Bellows (2)	C033	2.7
Propellant Isolation Valves (2)	C043	11.0
Helium Plumbing	A023	2.0
Propellant Plumbing	C033	8.6
Engine Exhaust Shields	C211	3.5
Contingency		3.4
Total		340.8
TT&C		
PCM TLM Type IV	A055	4.0
Baseband Unit, Type 3	A045	2.0

Table 2-2 (Continued)

	Code	Weight (lb)
TT&C (Continued)		
UHF Transmitter	A025	4.0
TLM J-Box	A035	5.2
Air-Conditioning Ducting	A074	3.9
Antenna	A065	0.6
RF Switch, Type 14	A075	0.6
Contingency		0.2
Total		20.5
GUIDANCE AND CONTROL		
Flight Control Electronics	A034	8.6
Inertial Sensor Assembly	A024	36.6
Guidance Computer	A014	46.8
Hydraulic Power Package	C063	8.7
Hydraulic Actuators (2)	C073	6.7
Nitrogen Tank	C014	21.2
Nitrogen Regulator	C034	7.9
N_2 Fill Valve	C044	0.3
Thrust Valve Cluster (2)	C053	9.2
Attitude Control Plumbing	C004	2.8
Nitrogen Temperature Probe	C024	0.5
Nitrogen Tank Fitting	C054	0.8
Hydraulic Plumbing	C083	3.0
Contingency		1.5
Total		154.6
Total Ascent Agena Configuration		1, 128.2

Table 2-3

MISSION-PECULIAR MODIFICATIONS TO BASELINE CONFIGURATION

	Weight (lb)		
	Planetary Injection	Synchronous Equatorial Injection	30-Day Mission
Baseline Configuration	1,128.2	1,128.2	1,128.2
STRUCTURE			
Remove: Roller Mechanism	-4.8	-4.8	-4.8
Add: Attachment Rings and Fittings	75.6	75.6	34.2
Add: Brackets for STD Deployment	10.0	10.0	10.0
Contingency	7.8	7.8	7.8
Total	88.6	88.6	47.2
PROPULSION			
Remove: Dual Start Kit	-7.8	-7.8	-7.8
Dual Start Kit	-1.9	-1.9	-1.9
Starter Grain Kit	-2.6	-2.6	-2.6
Starter Igniter	-1.2	-1.2	-1.2
Add: Propellant Dump Valves and Lines	2.8	2.8	2.8
Regulator Pressurization System	7.9	7.9	7.9
Multistart Kit	28.0	28.0	28.0
Contingency	4.2	4.2	4.2
Total	29.4	29.4	29.4
COMMUNICATION			
Remove: Baseband Unit Type 3	-2.0	-2.0	-2.0
UHF Transmitter	-4.0	-4.0	-4.0
Air-Conditioning Ducting	-3.9	-3.9	-3.9
Antenna	-0.6	-0.6	-0.6
RF Switch Type 14	-0.6	-0.6	-0.6

Table 2-3 (Continued)

	Weight (lb)		
	Planetary Injection	Synchronous Equatorial Injection	30-Day Mission
COMMUNICATION (Continued)			
Add: Decoder	2.3	2.3	2.3
Multicoupler	1.6	1.6	1.6
Receiver-Demodulator	9.0	9.0	9.0
Transmitter	3.5	9.0	3.5
Baseband Unit	1.0	1.0	1.0
Coaxial Cables	2.0	2.0	2.0
Omni-Antenna	1.5	1.5	1.5
Parabolic Antenna		9.0	
Contingency	6.3	7.9	6.3
Total	16.1	25.1	16.1
ELECTRICAL SYSTEM			
Remove: Primary Battery		-32.2	-32.2
Add: Primary Battery		120.0	
Secondary Battery			52.0
Solar Array			20.0
Charge Control			18.0
Cables			10.0
Contingency			5.0
Total	0	87.2	72.8
GUIDANCE AND CONTROL			
Remove: Flight Control Electronics			-8.6
Add: Status and Safety Checkout Sensors	10.0	10.0	10.0
DACS Mounting Hardware			26.5
Horizon Sensor Mixer Box (2)			22.0

Table 2-3 (Continued)

	Weight (lb)		
	Planetary Injection	Synchronous Equatorial Injection	30-Day Mission
GUIDANCE AND CONTROL (Continued)			
Add: Horizon Sensor Heads (4)			22.0
Gyro Reference Assembly (2)			40.0
Orbit Electronic Assembly			17.2
Augmented Electronic Assembly			20.2
Cable Assembly, Flat			5.5
N_2 Regulator			9.2
Wire Harness			2.5
N_2 Bottle, Spherical (1)			22.5
Plumbing			21.8
Contingency	1.0	1.0	4.7
Total	11.0	11.0	215.7
Total Configuration Dry Weight	1,273.3	1,369.5	1,489.4
He Gas	2.5	2.5	2.5
N_2 Gas	30.3	30.3	78.5
Propellant Loaded (UDMH/IRFNA) (60°F)	13,561.0	13,561.0	13,561.0
Total Configured Wet Weight	14,867.1	14,963.3	15,131.4

Table 2-4

MISSION-PECULIAR MODIFICATIONS (IMPROVED AGENA)

For the improved Agena using HDA, the configuration dry weight will increase by 27 pounds due to higher expansion nozzle extension.

	Weight (lb)		
	Planetary Injection	Synchronous Equatorial Injection	30-Day Mission
	1,273.3	1,369.5	1,489.4
100:1 Expansion Nozzle	27.0	27.0	27.0
Total Configuration Dry Weight	1,300.3	1,396.5	1,516.4
He Gas	2.5	2.5	2.5
N_2 Gas	30.3	30.3	78.5
Propellant Loaded (UDMH/HDA) (60°F)	13,954.0	13,954.0	13,954.0
Total Configured Wet Weight	15,287.1	15,383.3	15,551.4

NOTE:

Agena tug performance has been computed for propellant condition at both 60°F and 75°F. The nominal propellant loading will be 13,411 pounds for IRFNA/UDMH and 13,784 pounds for HDA/UDMH.

Table 2-5

WEIGHT BREAKDOWN FOR AGENA SUPPORT SYSTEM

	Cantilevered Support System	Extended Cradle Support System	Cantilevered Support With Payload Adapter
Agena/Payload Support Structure	508	1083	642
Agena Service Panel and Electrical Compartment	75	75	75
Dump Lines Retraction Mechanisms	103	103	103
Dump Lines	6	6	56
J-100 Disconnect	56	56	56
J-100 Cables	15	15	15
Cables for Deployment Control and Instrumentation	7	7	7
Propellant Dump Lines Within the Orbiter	11	11	11
Cables From Service Panel to Forward Bulkhead	15	15	15
TOTAL	796	1371	930

Note: If the Agena deployment system is used, the support weight will be increased by 300 pounds.

Table 2-6

WEIGHT SEQUENCE

	Planetary Injection		Synchronous Equatorial Injection		Low-Earth-Orbit 30-Day Mission	
	Agena IRFNA/ UDMH	Agena HDA/ UDMH	Agena IRFNA/ UDMH	Agena HDA/ UDMH	Agena IRFNA/ UDMH	Agena HDA/ UDMH
Total Agena Installed Weight (No Payload)	15,693	16,083	15,759	16,179	16,502	16,922
Less: Agena Support Weight	796	796	796	796	1,371	1,371
Agena Deployment Weight (No Payload)	14,867	15,287	14,963	15,383	15,131	15,551
Less: Impulse Propellant	13,395	13,756	13,291	13,646	13,043	13,399
Pre-Flows	10	11	30	33	60	66
Post-Flows	45	47	135	141	270	282
N_2 Gas Used	8	9	8	8	60	62
Agena Weight at Spacecraft Separation	1,409	1,464	1,499	1,555	1,698	1,742
Less: Propelled Residuals	48	72	48	72	48	72
Propellant Margin	63	68	57	62	140	135
Remaining N_2 Gas	22	21	22	22	18	16
Helium Gas	3	3	3	3	3	3
Agena Dry Weight	1,273	1,300	1,369	1,396	1,489	1,516

Section 3
SUBSYSTEM DESCRIPTIONS

Section 3
SUBSYSTEM DESCRIPTIONS

The baseline Agena space tug vehicle described in Section 2 consists of six subsystems; five comprise the Agena tug itself, while the sixth covers the support structure required to mount the Agena and its payload in the space shuttle orbiter cargo bay. These subsystems satisfy the requirements established in Part 1, with minimum modification or disturbance of flight-qualified configurations.

3.1 AGENA/PAYLOAD SUPPORT STRUCTURE

A number of mechanical support alternatives were investigated to find the most efficient attachment for the Agena and payload in the orbiter cargo bay. Three designs that satisfy the guidelines and interface requirements were selected. The choice among the three concepts depends primarily upon the payload configuration.

3.1.1 Cantilevered Payload Support Cradle Concept

This concept, which is shown in Fig. 3-1, has the payload cantilevered off the Agena forward interface ring at Station 247. The Agena is supported by a cradle attached to the orbiter structural sidewalls and the lower keelson. The cradle utilizes a truss structure with members made of 2219 aluminum alloy tubing welded together at the member junctions to transmit the loads from the Agena/payload to the orbiter structure. The truss members are assembled in a geometric shape that lies within the 180.0-inch-diameter cargo bay space envelope interfacing with the orbiter attach fittings. Diagonal members at the fore and aft end of the cradle transmit the vertical forces from the Agena to the keelson of the orbiter. The utility of this concept is constrained by the structural capability of the Agena forward section. The maximum allowable weight and CG location can be determined from Fig. 3-2, a curve for no payload adapter. This concept would appear to be most attractive for transporting spacecraft such as communication satellites or other types of payloads having a low density but a large volume and a

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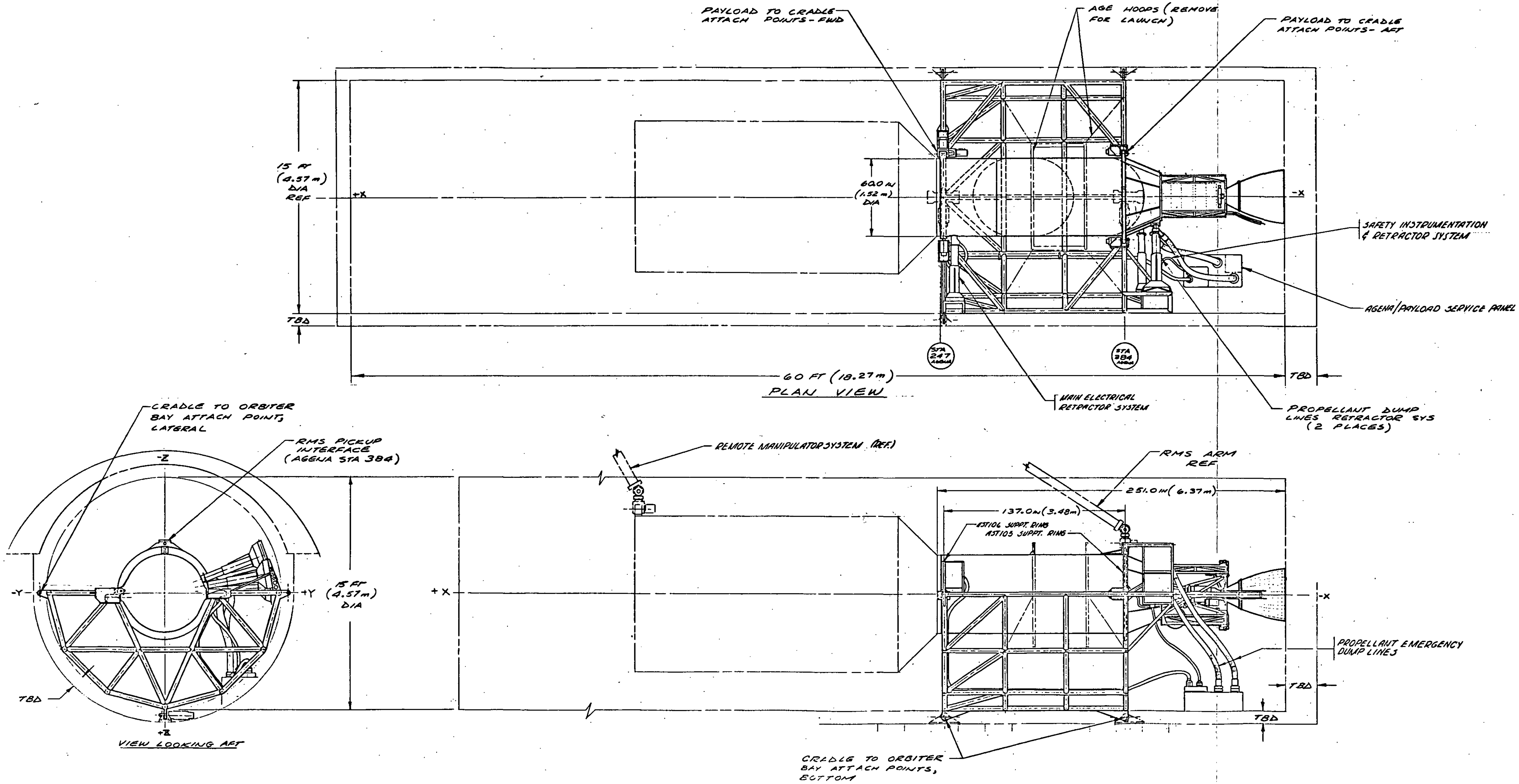

Fig. 3-1 Agena Tug/Orbiter Cantilevered Support Cradle Interface

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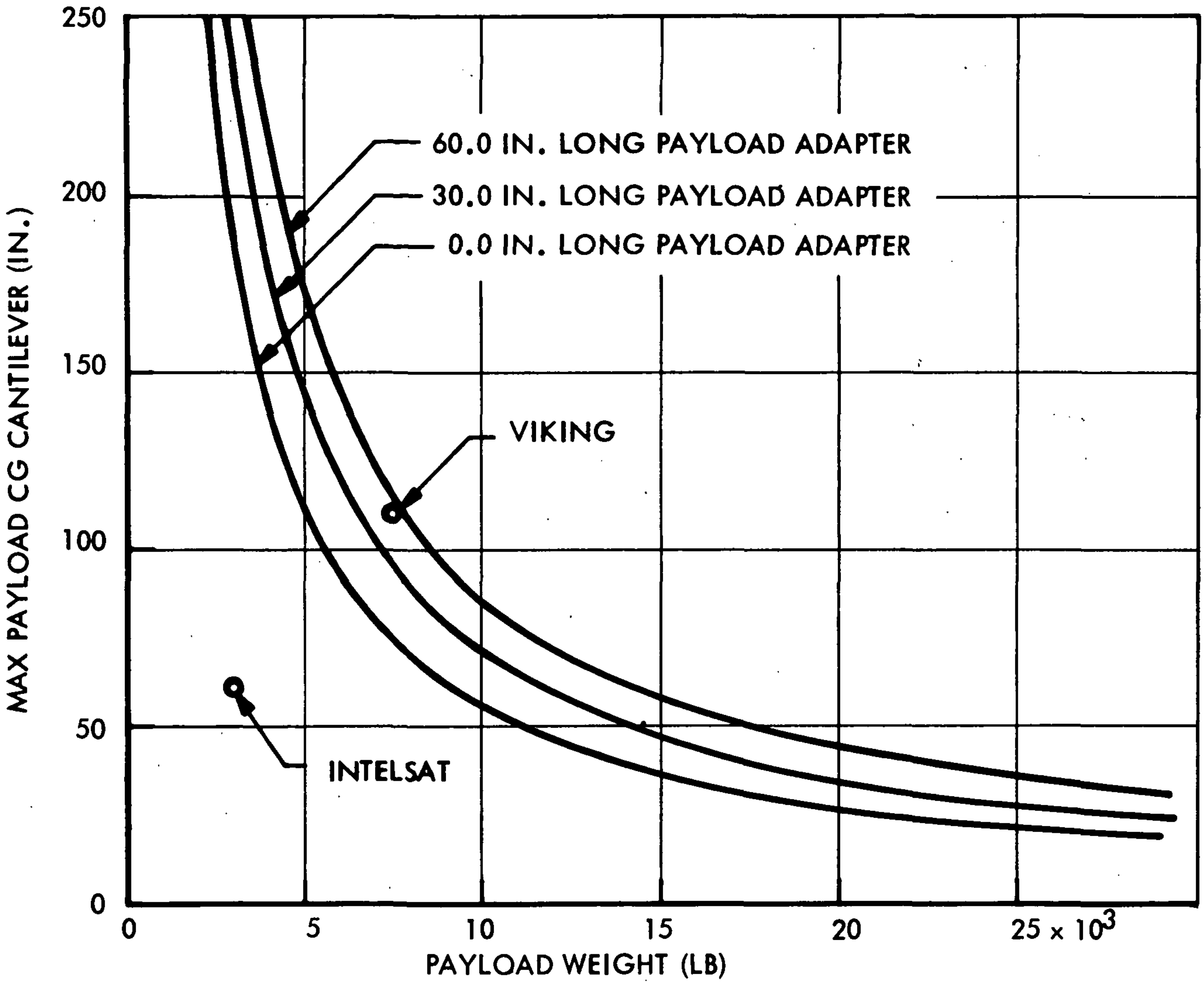

Fig. 3-2 Maximum Payload CG Cantilever Distance Versus Payload Weight (Landing Condition)

bulky profile. The cradle-type support system is easily adaptable to all ground handling activities with both Agena vehicle and the mated payload; however, it will be necessary to provide an attachment on the payload forward of the payload/Agena CG when hoisting the mated payload and Agena with the Agena propellant tanks empty.

This concept requires the addition of rings located at Agena Station 247.0 and Station 384.0 to increase the Agena structural capability at the main load attachment points. The detail design of these rings is discussed in par. 3.2. Figure 3-3 shows the direction and axis orientation of the Agena/payload forces from the orbiter cradle. These forces will be reacted by large pins which extend into a cavity of the Agena new payload supporting rings.

To provide added protection against damaging the tank structure while the propellant tanks are full during ground handling and orbiter erection mode, two rings will be installed around the tank periphery between the Agena forward and aft rings as a temporary structural reinforcement. These rings will be removed after the Orbiter/Agena has been erected on the pad in a vertical position.

3.1.2 Extended Cradle Support Concept

This concept, shown in Fig. 3-4, also includes a truss-type cradle that extends from Agena Station 383.85 forward to the payload CG. The system is designed to support a payload corresponding to the maximum orbiter payload weight of 65,000 pounds. Since the spacecraft weight in this case exceeds the Agena structural capability for the cantilevered system, the forward truss members are designed to transmit payload forces directly to the orbiter structure. The truss members located at the payload CG and the aft support structure located at the Agena Station 383.85 are made of 321/347 CRES tubing. The intermediate truss members are made of 2219-T81 aluminum alloy tubing. The truss members are assembled geometrically to fit within the 180-inch-diameter cargo bay envelope.

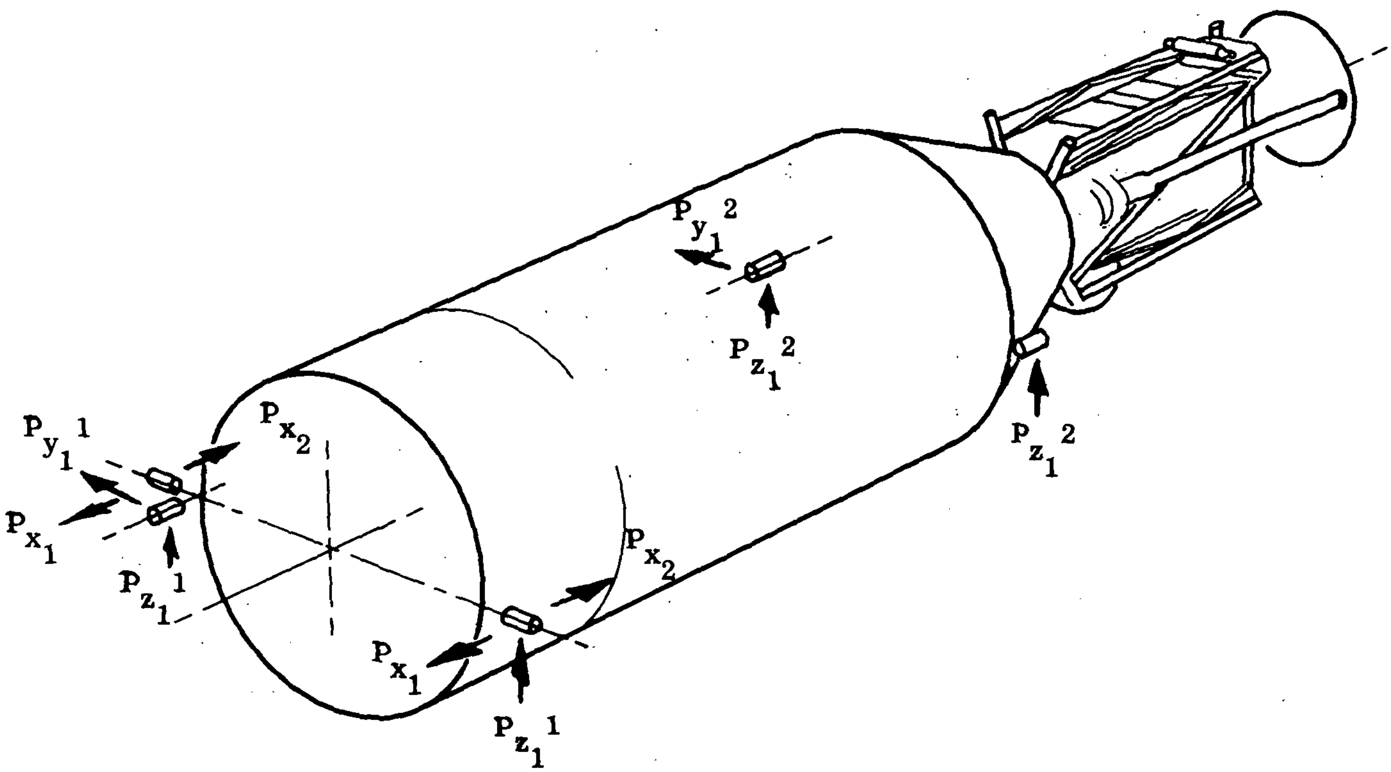

Fig. 3-3 Agena/Payload Forces

To accommodate a wide variety of payload configurations, the cradle has been designed as a modular assembly incorporating a detachable forward section that permits the addition or deletion of truss center sections. The removable forward section is the most loaded part; however, the entire cradle has been designed to accommodate the maximum orbiter payload weight. Both these two concepts utilize four attachment points, two on the payload bay side and two on the keelson.

The extended cradle concept also makes use of removable rings to preclude damage to the Agena tank structure during ground handling and orbiter erection. An isometric drawing of this concept is shown in Fig. 3-5.

3.1.3 Cantilevered Support Cradle With Payload Adapter

The payload weight-CG limitation for a cantilevered support arrangement is shown in Fig. 3-2. This limitation, based on the structural capability of the Agena forward section can be improved somewhat by using a payload adapter as shown in Fig. 3-6. In this case the configuration is supported at Agena Station 384 and at the payload interface station; the bending moment at the Agena interface Station 247 is thereby reduced. This support arrangement, which is somewhat in between the two systems previously described, can be used for any spacecraft configuration suitable for cantilevered suspension. Figure 3-2 shows that a 60-inch adapter will provide sufficient capability to accommodate the Viking spacecraft. This adapter is, however, estimated to weigh 350 pounds and, since it stays with the Agena until spacecraft separation, it represents a direct 350-pound loss in payload capability. The adapter could, however, be incorporated as an integral part of the spacecraft structure.

The support structure is again a tubular truss frame utilizing 2219 aluminum alloy tubing welded at the member junctions. This cradle is suspended at four attachment points to the orbiter structure on the sidewalls of the orbiter cargo bay. The configuration shown in Fig. 3-6 also indicates the structural interface between the cradle and the orbiter structure and the tiedown mechanisms.

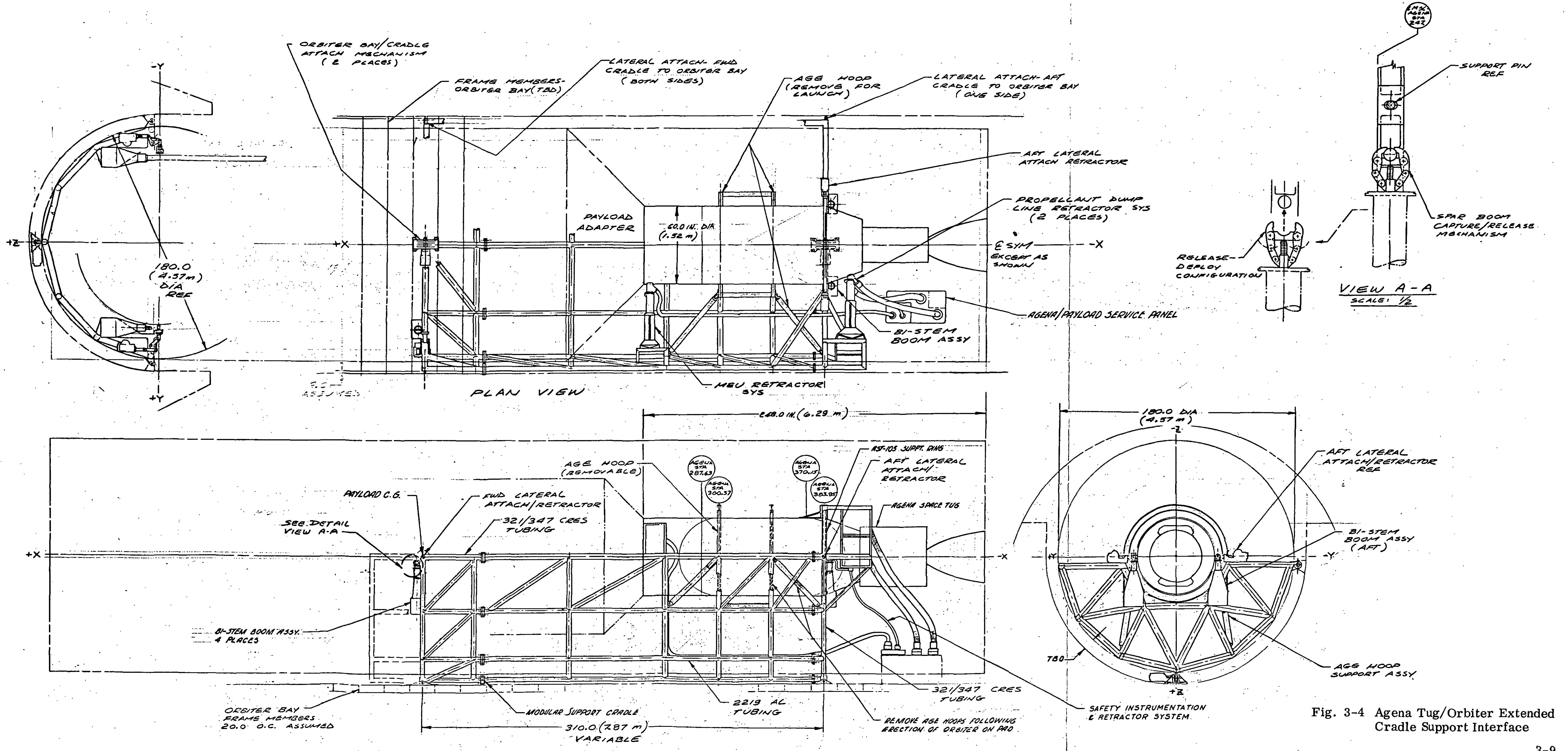

Fig. 3-4 Agena Tug/Orbiter Extended Cradle Support Interface

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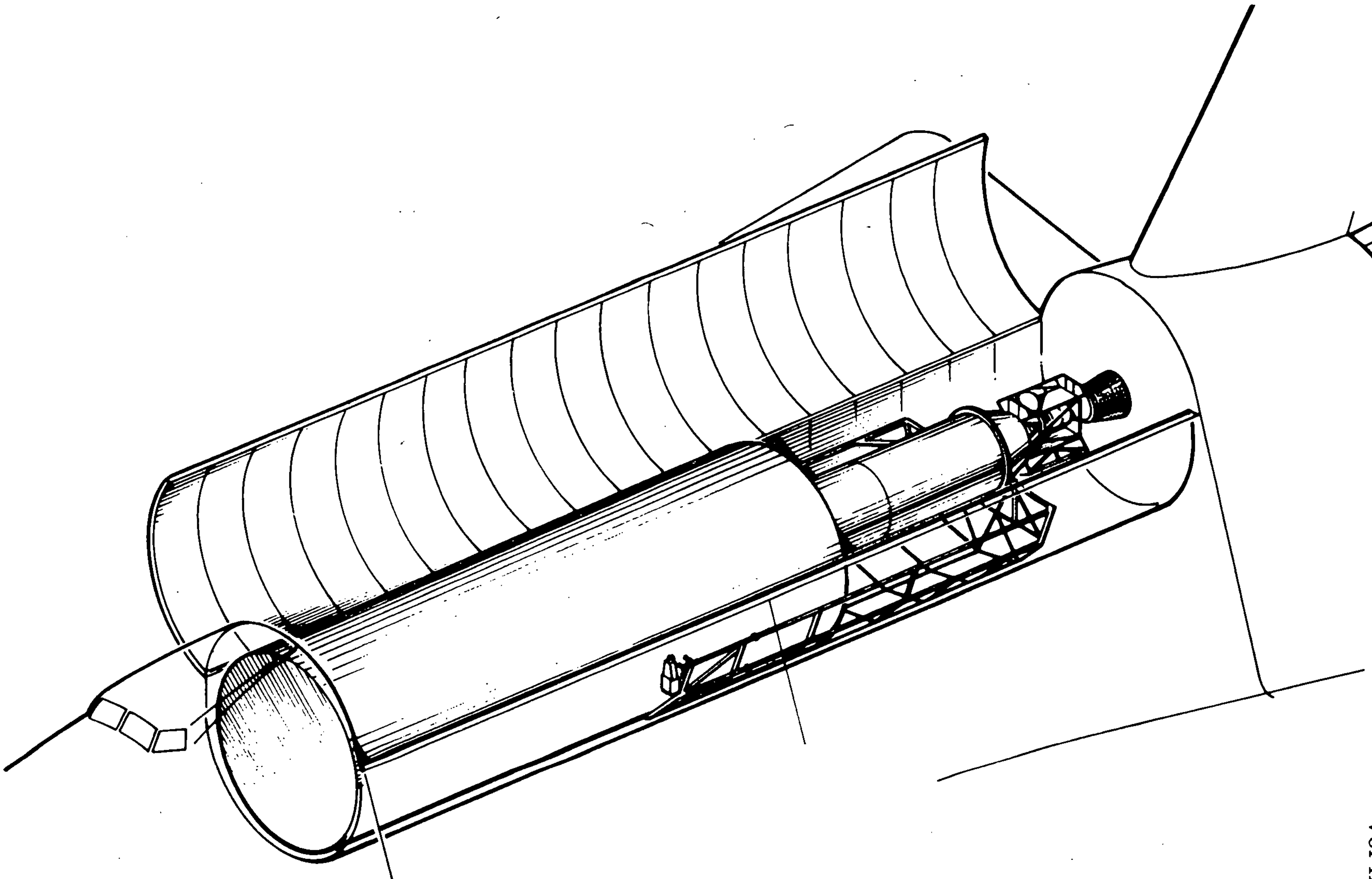

Fig. 3-5 Extended Cradle Support

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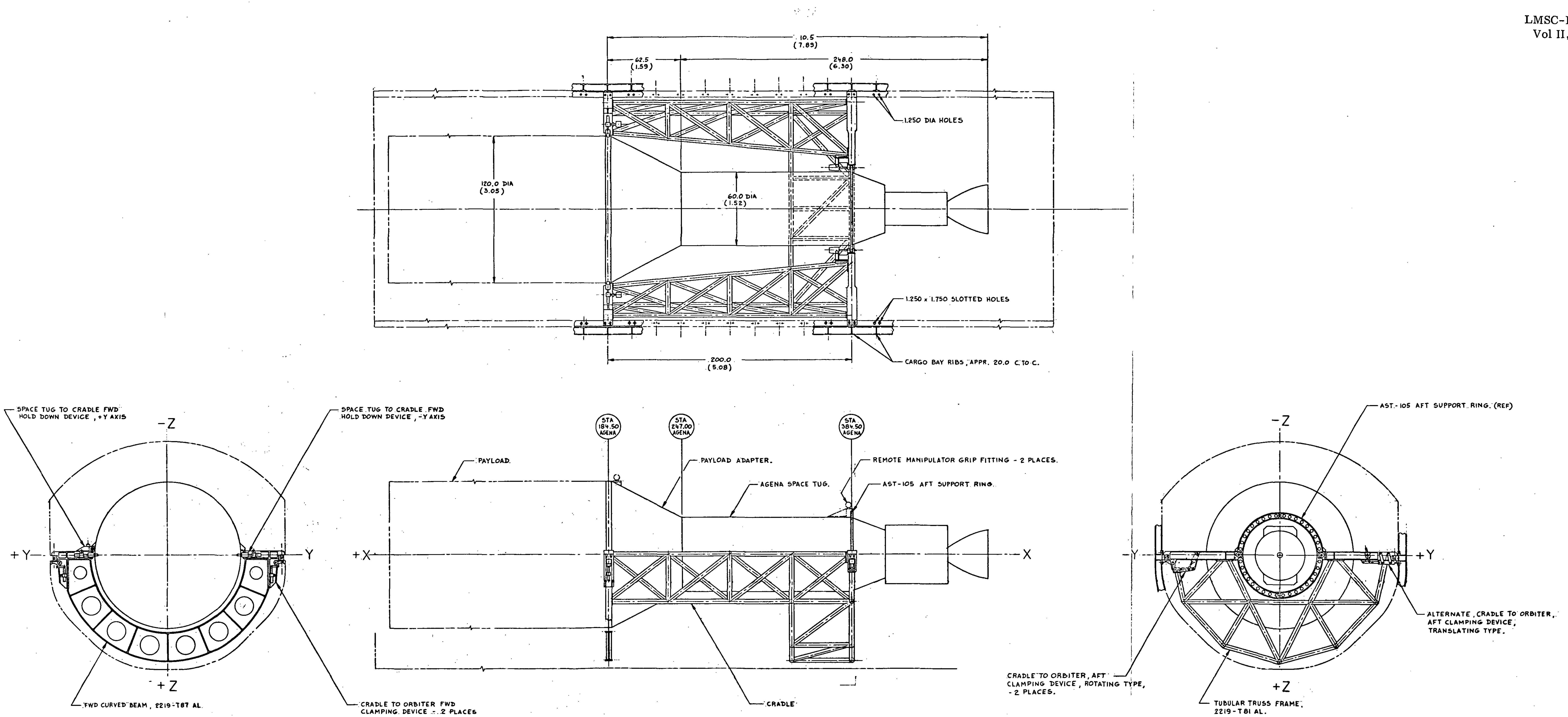

NOTE: DIMENSIONS IN (.) ARE METERS.

Fig. 3-6 Agena Space Tug/Orbiter Cantilevered Support Cradle With Payload Adapter Interface

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3.1.4 Agena-To-Cradle Attachment System

Figure 3-7 shows the detail design features of the Agena/payload-to-cradle supporting system, which transmits the inertia forces to the truss-type cradle. This system utilizes large-diameter pins installed in a bracket attached to the cradle, with the pins extending through receptacles provided as fittings integral with the rings at Agena Stations 247.0 and 384.0 (depending upon the cradle concept used). Shims and slotted holes are provided in the pin support brackets to facilitate alignment and mating of the Agena and cradle. The axis of the pins will be oriented to ensure that the loads are reacted normal to the pin center lines in the intended direction, as shown in Fig. 3-3. The pins, made of A-286 heat-treated CRES, are tapered to further assist in aligning the center lines at installation. The pins will be machined to a surface finish of 64 RMS for smooth contacting surface. A baseplate, made of heat-treated CRES, is welded to the cradle structure for attaching the pin support fitting,which is made of 7075-T73 aluminum forging. The fitting is slotted or forked to allow double shear on the pin. A-286 CRES chemically treated bushings are pressed into the lugs to increase the bearing strength of the fittings and decrease brinelling.

It is planned that the actuators will be electrically driven screws, which minimize the number of system components. The actuator screws are installed so that only the force required to translate the pins will be imposed on the actuator system. The actuator incorporates a backup system that provides for manual extraction of the retention pins in the event of electrical or mechanical failure. A hand-operated crank is stowed adjacent to one of the actuators.

A limit switch at the retractor for each pin will provide a signal to the orbiter main control panel that power is on at each actuator. Another signal (colored lights) will appear, confirming that pin-pulling has been completed and the pins are free of the Agena receptacles and supporting brackets.

3.1.5 Support System Structural Loads

The interface loads between the Agena/payload support cradle and the orbiter structure were evaluated for a limited number of flight conditions and payload weights. For the cantilevered and extended cradle support systems, four attachment points with five load reactions are used (Fig. 3-8). The four structural hardpoints are located two on the cargo bay sidewalls and two on the keelson. For the cantilevered support with payload adapter, a four-point attachment was also used, but these points are all located on the cargo bay walls, as shown by Fig. 3-9, resulting in lower loads and therefore lower structural weights for both the payload support system and the orbiter structure.

The support load components for these configurations are shown in Table 3-1 for the configurations shown in Fig. 3-8, and in Table 3-2 for the loading condition shown in Fig. 3-9. For the cantilevered support system a payload weight of 7,600 pounds, corresponding to the Viking spacecraft was used, and for the extendible cradle support the maximum payload weight for landing condition was used (40,000 – 1,300 – 1,600 equals 37,100 pounds).

The loads listed represent ultimate loads, including a safety factor of 1.5. A more complete analysis of the load spectrum must be performed; however, the loads listed in Tables 3-1 and 3-2 are considered to be a reasonable indication of the loads that the orbiter structure must be designed for.

3.1.6 Agena Deployment Systems

The Agena/payload configuration can be deployed from the cargo bay by use of the orbiter remote manipulator system, as shown in Fig. 3-10. Fittings for grouping the Agena and the payload will then be included on the structural rings to be added to the Agena and the payload configuration. These fittings will be designed to resist forces and moments about all three axes.

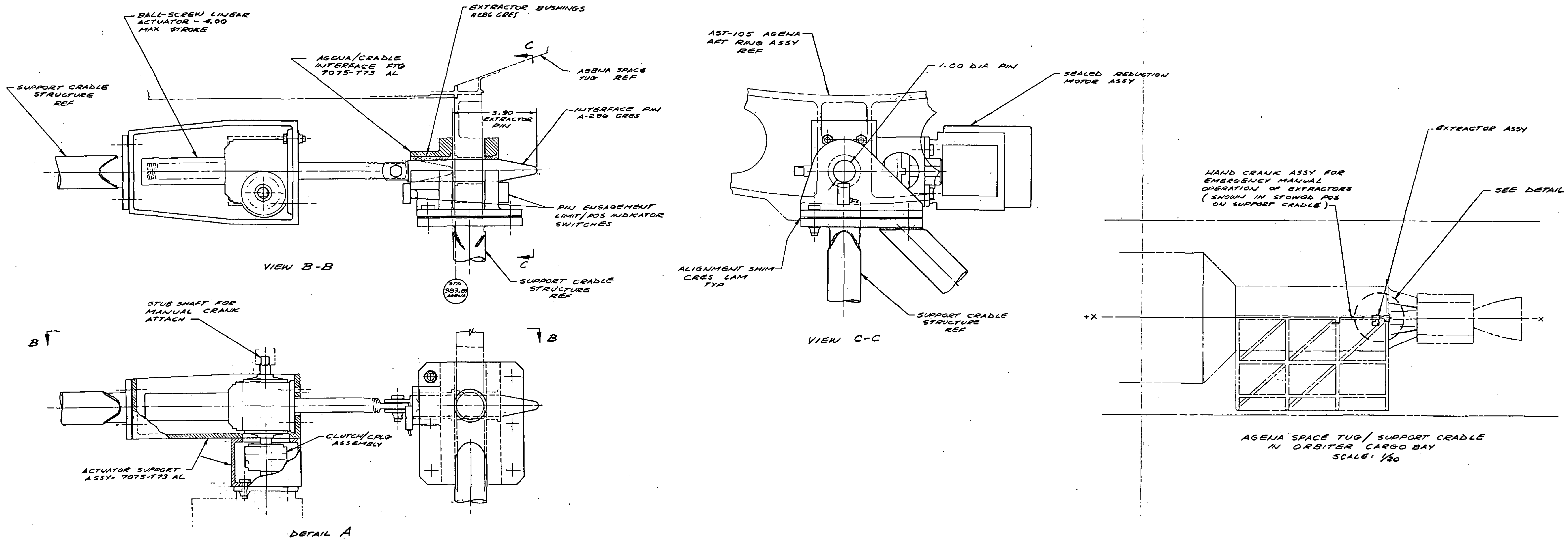

Fig. 3-7 Agena Tug/Support Cradle
Extractor Assembly Detail

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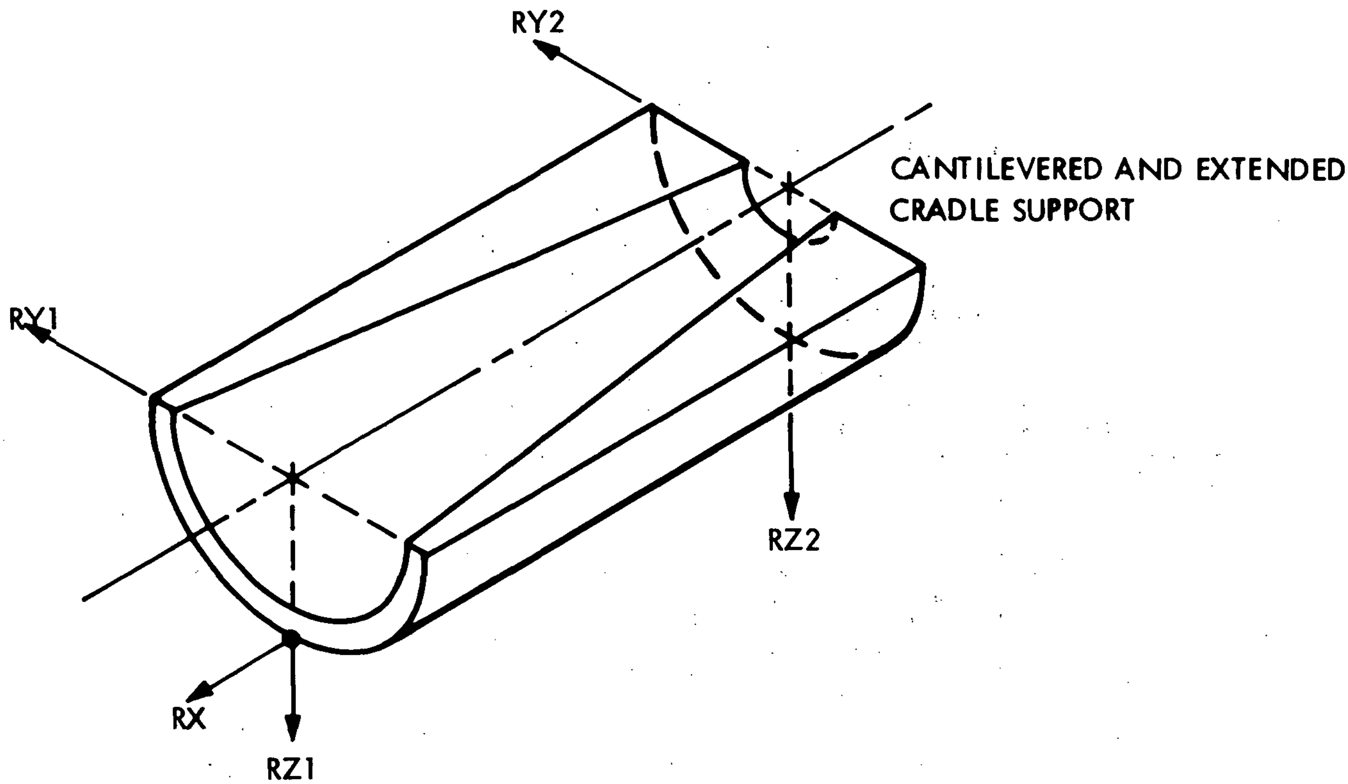

Fig. 3-8 Interface Load Reactions – Cantilevered and Extended Cradle Support

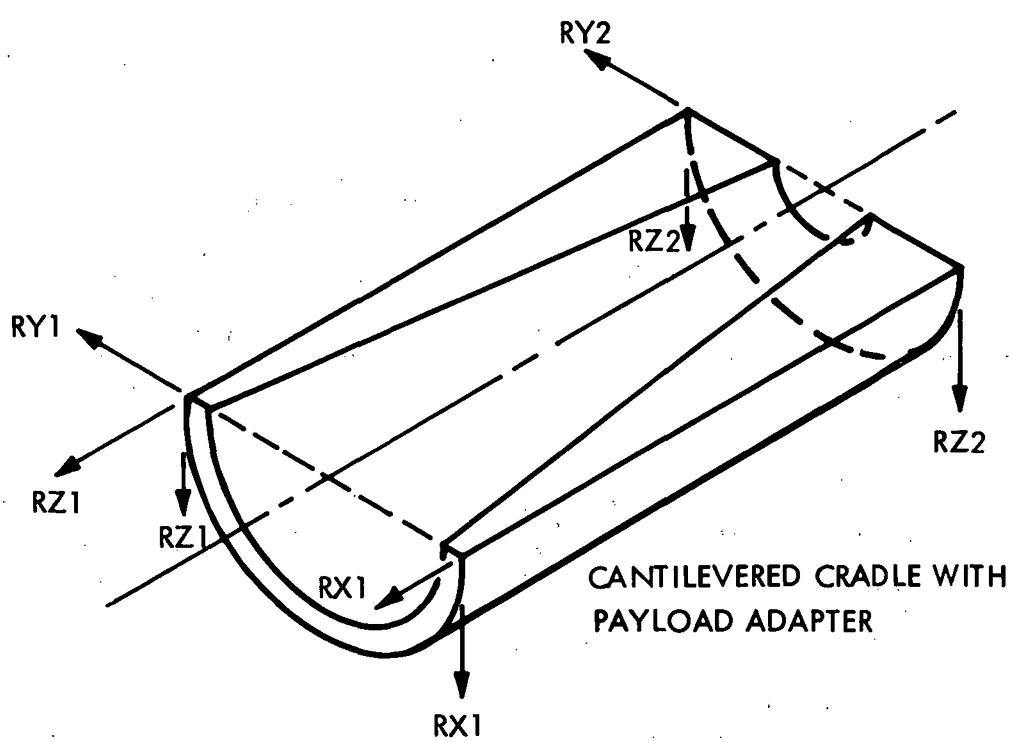

Fig. 3-9 Interface Load Reactions – Cantilevered Cradle With Payload Adapter

Table 3-1

INTERFACE LOAD REACTIONS FOR FIG. 3-8

Agena: 15,000 lb at BECO*
1,300 lb at Landing
Cantilevered Payload: 7,600 lb
Cantilevered Support: 960 lb
Supported Payload: 37,100 lb
Support Cradle: 1,600 lb

Load Factor	BECO (g)		Landing (g)	
N_x N_y N_z	+3.2 ±0.5 -0.6		-1.3 ±0.5 -2.7	
	Cantilevered Payload (lb)	Supported Payload (lb)	Cantilevered Payload (lb)	Supported Payload (lb)
Rx	78,000	177,000	-12,300	- 52,000
Ry1	± 8,800	± 20,000	± 6,720	± 19,000
Ry2	± 3,200	± 7,000	± 2,000	± 1,100
Rz1	35,100	25,200	-43,300	-117,000
Rz2	-50,200	- 57,200	-17,700	8,800

*Booster Engine Cutoff

Table 3-2

INTERFACE LOAD REACTIONS FOR FIG. 3-9

Agena: 15,000 lb at BECO
1,300 lb at landing
Payload: 7,600 lb
Payload Support: 1,100 lb

Load Factor	BECO (g)	Landing (g)
N_x N_y N_z	+3.2 ±0.5 -0.6	-1.3 ±0.5 -2.7
	Cantilevered Support With Payload Adapter (lb)	
Rx1	41,000	- 6,700
Rx2	41,000	- 6,700
Ry1	± 7,850	± 6,500
Ry2	± 4,200	± 1,350
Rz1	- 4,700	-17,500
Rz2	- 2,500	3,600

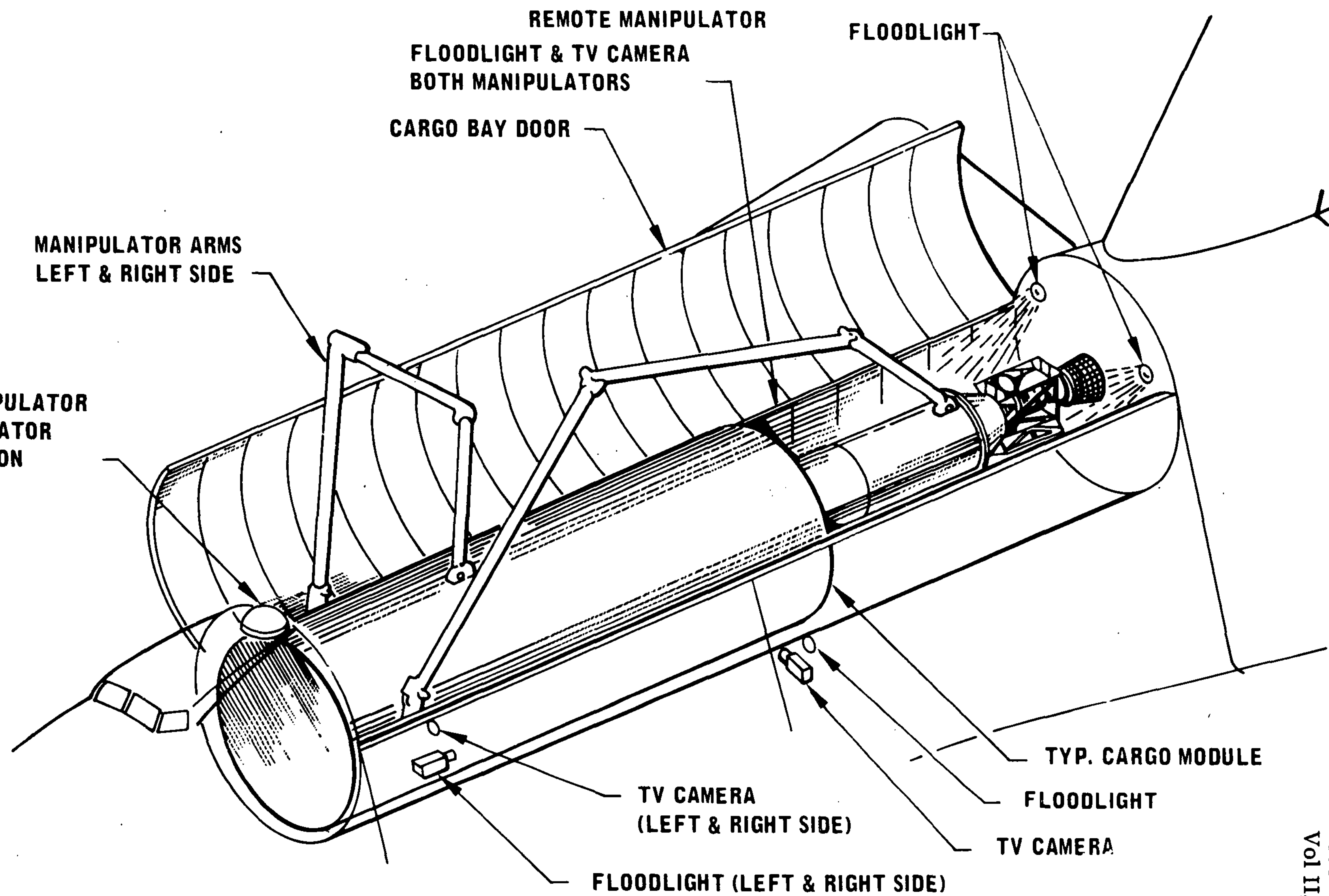

Fig. 3-10 Deployment System

An older mode deployment system using extendible booms is shown in Fig. 3-11 and, in more detail, in Fig. 3-4. This system uses four bi-STEM boom devices permanently attached to the payload support truss adjacent to the Agena/payload supporting points. The extendible portion of the boom is attached to the Agena/payload with off-center latches, which will be opened prior to pulling the main attaching pins. Electrical motors will be actuated to drive the bi-STEM booms from the storage spools. The motors will have a synchronization device to ensure uniform extension of the four booms. At the end of the boom travel the Agena/payload release can either occur automatically or the release could be delayed pending additional payload checks that could not be performed inside the cargo bay.

The STEM (storable tubular extendible member) is a tape or element of thin stainless steel that assumes a tubular shape when extended. It can be stored in a minimum of space when coiled in the flattened condition on a spool. The spool diameter is chosen so that the elastic limit of the tape material is not exceeded when it is coiled. In this way no permanent strain is introduced in the tape, thus guaranteeing that it always returns to its tubular form even after repeated extension and retraction cycles. The bi-STEM when extended has approximately the same structural characteristics in tension and compression as the equivalent size tubing having the same wall thickness. The fundamental law of STEM forming is that the STEM is free of stress in its natural shape as a straight tube of a given diameter. By attaching the element to a storage spool and winding it up, strain energy is stored in the element with the net result that it tends to self-extend. The stresses created in the coiled, flattened element are then a maximum. Flattening of the element is a gradual process and takes place over a finite distance, within the storage housing.

The STEM, manufactured by Spar Aerospace Products, Ltd., has been used successfully in many aerospace programs, including the Apollo program. However, it is recommended that more extensive study and investigation be conducted for this application, including dynamic analysis, structural and thermal analysis, actuator synchronization, and power supply.

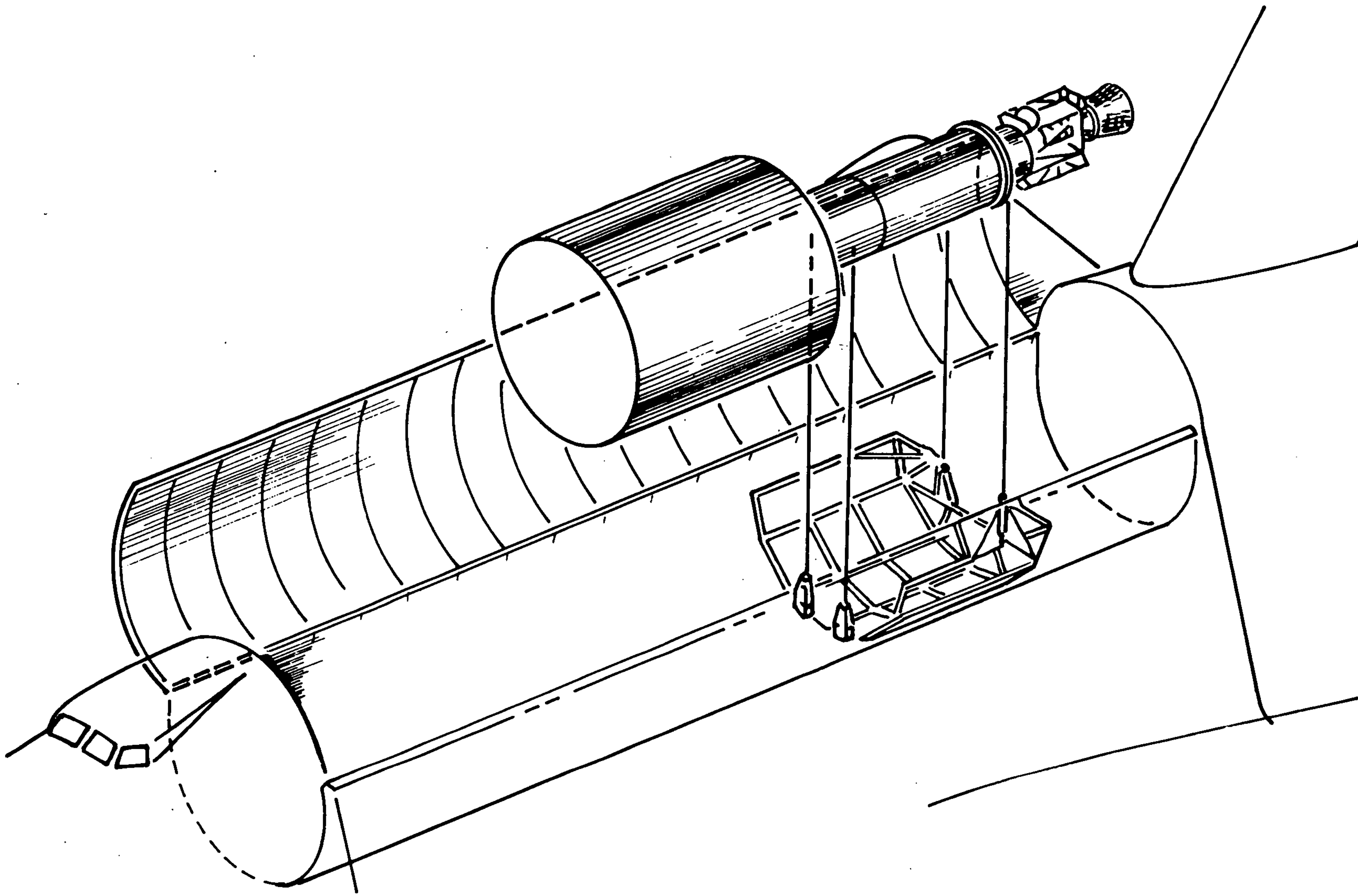

Fig. 3-11 Alternate Deployment System
(Extendible Booms – Short Support Cradle)

This deployment system is proposed as an alternate to the remote manipulator system. It is believed that the extendible boom concept has several advantages, such as simplicity and ease of operation. The weight of this system is indicated to be 300 pounds, and it is recognized that this weight will be charged to the Agena system if it is included. This weight will, of course, stay with the orbiter so the payload capability of the Agena vehicle is not affected.

3.2 STRUCTURES SUBSYSTEM

The basic ascent Agena structure can meet the requirements for the Agena tug mission applications without modification, except for the loads encountered during ascent (or reentry and landing in the event of an abort) when the Agena and its payload are installed in the orbiter cargo bay. These loads, and therefore the modifications, are dependent on the support concept employed for the Agena/payload combination.

3.2.1 Modifications for Extended Cradle Support

In the extended cradle support concept the Agena/payload assembly is attached to the cradle at four points. The two forward points are located on each side of the payload, at or near the Y-Y axis and at a station as close as possible to the CG of the payload. The structural frame of the payload will provide the attach fittings required for the holddown devices to fasten and release the payload to and from the cradle. A two-piece ring is added to the Agena outer mold line at Station 384, which provides two attachment hard points at or near the Y-Y axis. The ring is installed in two pieces to compensate for variations in external contour or eccentricity that might occur during fabrication. Shims can be used at the mating joint to adjust the rings to the existing Agena vehicle contour. The ring, as shown in Fig. 3-12, is manufactured from a 7075-T73 aluminum forging. A C-channel was selected as the cross-section for this ring, for its high moment of inertia and simplicity of installation. The web has lightening holes to reduce weight. The inner cap of the ring is bolted to the Agena transition ring by 174 titanium cap screws utilizing existing nut plates riveted to the Agena engine cone ring. Pure aluminum foil is inserted between the two-piece ring and the magnesium engine cone ring to prevent dissimilar metal catalytic corrosion. The two halves of the ring are bolted together with interposition of laminated shims that can be removed or added as required.

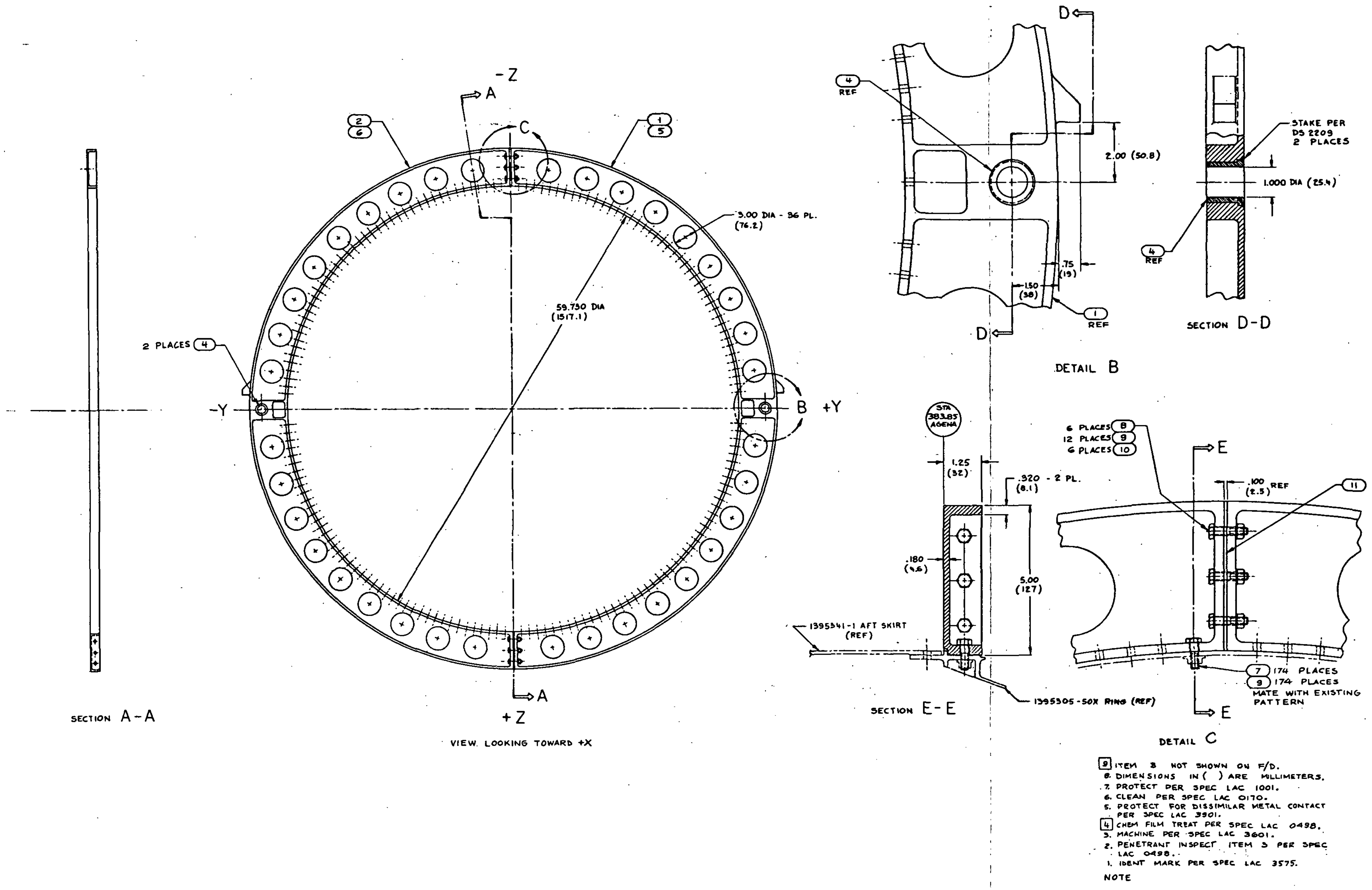

Fig. 3-12 Agena Tug Aft Support Ring

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Two stainless-steel bushings are pressed and staked into the aluminum forgings to provide smooth and positive attachments to the retractable pin type holddown devices installed on the cradle.

This support ring will transmit to the aft end of the payload/Agena assembly the vertical and lateral loads imposed by the flight loads of the orbiter. The forward attachments at the payload CG are designed to transmit all axial loads to the vehicle as well as the vertical and lateral loads imposed to the forward end of the assembly. A preliminary calculation shows that the payload/Agena interface attachments at Agena Station 247.0 are capable of absorbing, with a large margin of safety, all tension loads and bending moments induced during all phases of the mission. Two stops are provided on each side of the ring on the Y-Y axis to assure that the Agena will not accidentally strike any part of the structure when the vehicle assembly is lowered into the cradle. These stops will also assist in the alignment of the holes in the ring with the pins of the holddown devices. Similar stops should also be provided on the payload support frame to avoid equipment damage during installation of the assembly into the cradle.

The bushings and pins of the attachment devices will be machined to a surface finish of 64 RMS for smooth contacting surface. All pins and bushings are made of A-286 CRES heat treated for higher mechanical properties.

3.2.2 Modifications for Cantilevered Support Cradle

The cantilevered payload support concept requires the addition of a forward ring at the payload interface of the Agena vehicle to react the inertia forces at this payload support point. The forward support ring, as shown in Fig. 3-13, is installed at Agena Station 247. An aft support ring installed at Agena Station 384.0, similar to the ring used for the extended cradle support concept, is also required. The cap and web thicknesses will be adjusted to meet the new load required by the cantilevered concept.

The forward support ring is machines from a one-piece forging of 7075-T73 aluminum and features also a C-shaped cross-section. This ring is sandwiched between the existing Agena forward rack section and the payload attaching ring. Eight 1/2-inch diameter bolts are used at both interfaces, and the bolt patterns are coincidental. The ring is equipped with three stainless steel bushings pressed and staked into the aluminum forging to receive the pins of the holddown devices, which will transmit the inertial loads from the cradle to the Agena space tug and payload. The two bushings on the Y-Y axis will transmit the axial and vertical loads, while the remaining bushing will transmit the lateral loads. Two stops are also provided on opposite sides of the ring to facilitate alignment of the pins with the mating holes in the ring and also to prevent accidental damage to the vehicle during installation in the cradle. The bushings and pins of the attachment devices will be machined to a surface finish of 64 RMS for smooth contacting surface. All pins and bushings are made of A-286 heat treated CRES for higher mechanical properties.

3.2.3 Modifications for Cantilevered Support Cradle With Payload Adapter

Using a payload adapter with the cradle support at the forward end made it possible to base the design on the structural capability of the existing Agena forward section, thus eliminating the need for the addition of a forward ring. This configuration, shown in Fig. 3-6, uses the same aft ring design as the two previously discussed configurations.

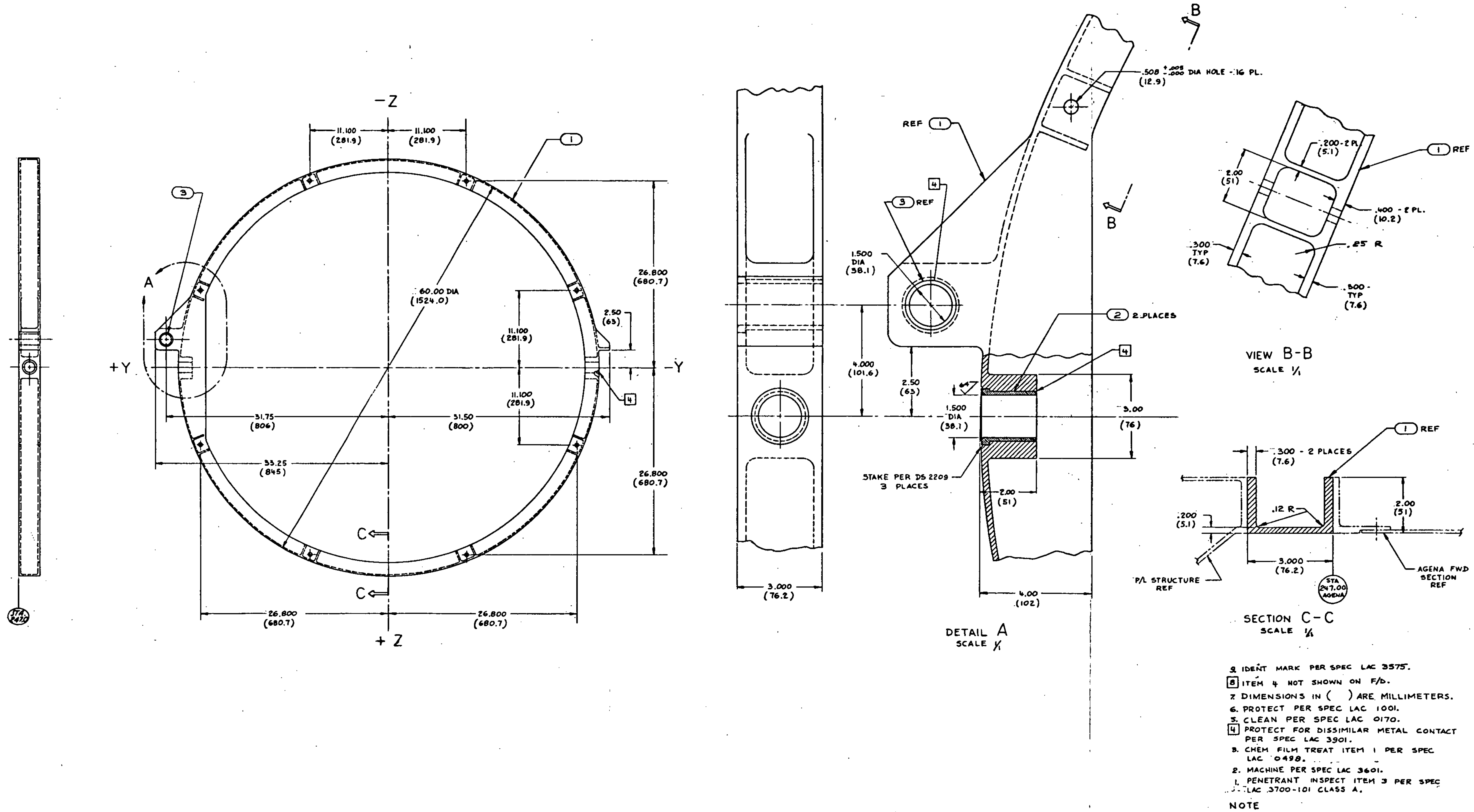

Fig. 3-13 Agena Tug Forward Support Ring

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3.3 PROPULSION SUBSYSTEM

The basic requirement of the propulsion subsystem is to provide the vehicle impulse to attain the velocity increment, or increments, required by the mission. Depending upon the type mission flown, the subsystem may provide single-, dual-, or multiple-burn periods of various duration within the total burn time capability without impairing the structural integrity of the vehicle and with operating characteristics satisfactorily controlled to yield the accuracy required for mission success.

The requirements as presently envisioned for the Agena space tug applications are as follows:

a. Multistart (Minimum of 15)
b. Restart After 30 Days
c. Restart After 10 Seconds of Engine Burn
d. Vertical and Horizontal Ground Hold Attitudes (Loaded with Propellants)
e. Emergency Propellant Dump in Orbit and While Vertical on Pad

The above requirements may be divided into two categories: shuttle-related requirements and mission-related requirements. The basic Agena propulsion system and its components are described in Annex A.

3.3.1 Shuttle-Related Propulsion Design Requirements

Unique propulsion system design requirements related to use of the Agena vehicle with the shuttle orbiter can be identified in three areas: emergency propellant dump; possible modifications to the engine gearbox to prevent oil leak at horizontal vehicle orientation while on the ground, and associated ground support equipment (GSE) necessary to handle propellant loading and status monitoring.

3.3.1.1 Emergency Propellant Dump. For safety reasons, provisions must be made to dump the Agena's propellants while it is contained in the orbiter cargo bay. The propellants will be dumped whenever an emergency or mission-aborting condition is encountered that would require the orbiter to land without deploying the Agena and its

attached payload. This capability is also desired on the pad during the launch countdown, when the vehicle is vertical. Consideration was also given to extending dump capability to all ground operating periods, including periods when the fueled Agena is horizontal. However, since no demanding situations could be identified in support of horizontal dump capability, no design modifications to the vehicle are planned.

The following design solutions were considered in the propellant dump evaluations:

- Use of existing flight dump capability
- Modification of fill system to permit dumping through existing lines
- Addition of tank penetrations and lines to permit horizontal dumping attitude

Using the existing dump capability of the Agena would require 76 and 39 minutes respectively for oxidizer and fuel, assuming a constant tank pressure of 55 psia. Dumping through the propellant fill lines can reduce the oxidizer and fuel dumping times to 9 and 5 minutes respectively for sequential dumping and further, to 9 minutes, if simultaneous dumping is selected. After these methods of dumping the propellants were reviewed it was concluded that use of the present fill lines would result in adequate dumping rates and would require the minimum of hardware modifications. These dump lines are schematically shown in Fig. 3-14.

Prior experience supports simultaneous dumping as both safe and practicable. In this case the oxidizer valve is opened first, and the fuel valve approximately 3 minutes later. The Agena, for safety reasons, generally will not be pressurized to 55 psia while it is in the orbiter cargo bay. For normal operation the full pressure will first be attained during the automatic countdown procedure. For an abort case the tank pressure will be raised to 55 psia as part of the dump routine.

At the completion of orbit dump the engine and tanks will be completely evacuated. Although propellants will still be trapped in the multistart engine start tanks, this condition is considered acceptable from a safety standpoint and there is no significant weight impact. At present it is therefore recommended that these propellants not be dumped.

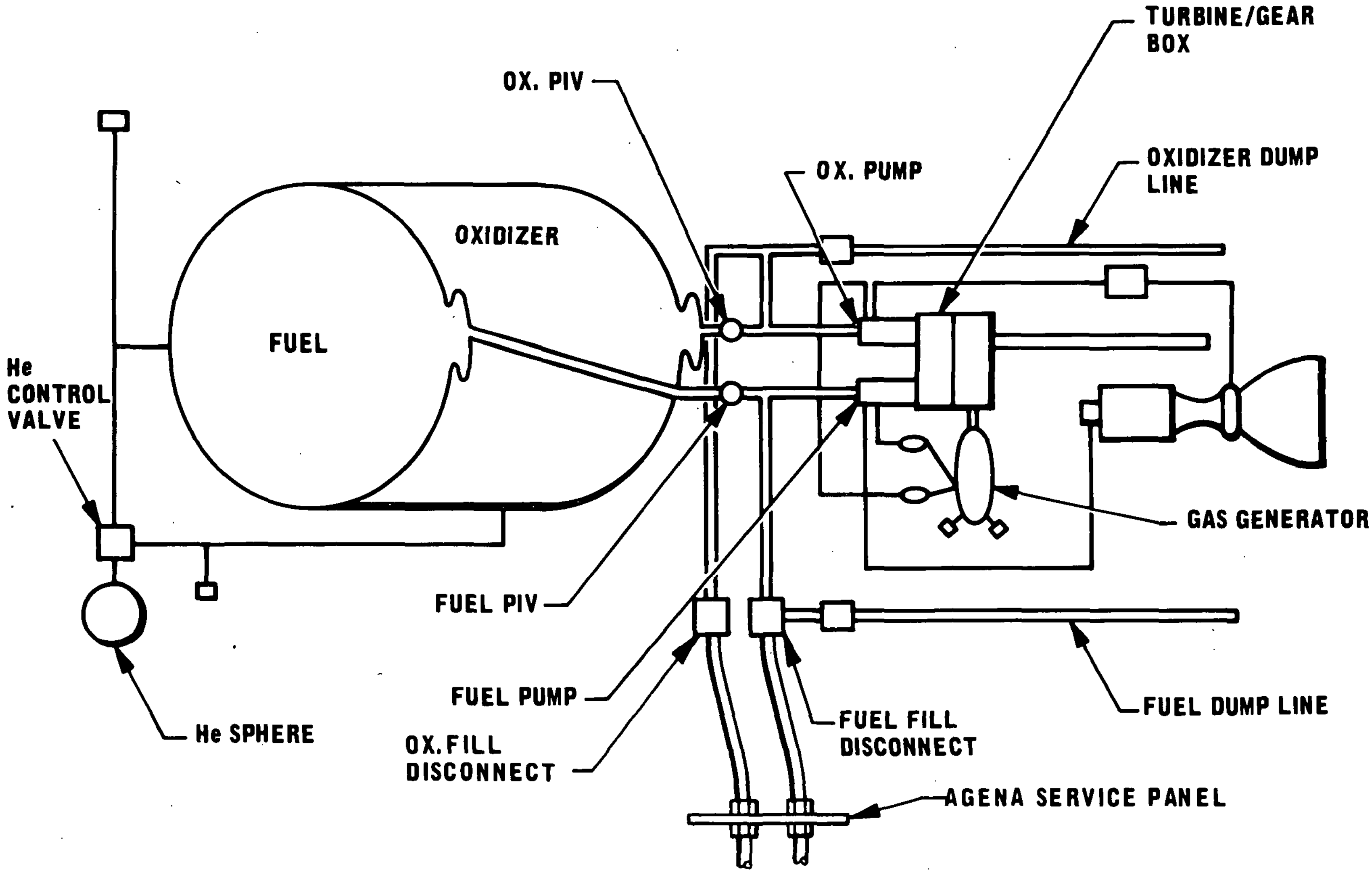

Fig. 3-14 Propellant Dump Lines

For orbital dump operation propellant location control must be provided by the orbiter. An acceleration of 10^{-2} to 10^{-3}g is required to keep the propellants settled in the aft end of the propellant tanks.

The oxidizer and fuel lines could remain open throughout reentry; however, structural considerations may require that a positive pressure be maintained in the tanks during reentry and landing.

If repressurization of the tanks is required the helium pressurization system could be modified to prevent complete loss of the pressurant gas during dump. The complexity of this type modification may be undesirable; therefore, a system such as illustrated in Fig. 3-15 has been proposed. In this concept the helium sphere would not be required to supply the repressurizing gas. Following dump completion the PIVs would be closed and high-pressure nitrogen gas contained in the attitude control system used to pressurize the tanks on a blowdown arrangement. Flow control orifices would assure proper differential pressure during the blowdown process. Fuel-oxidizer tank isolation, necessary for system safety, although not shown in the illustration, would be provided in the nitrogen supply lines. Redundant isolation of the high-pressure nitrogen would also be desirable from a reliability and safety standpoint.

3.3.1.2 Dump Line Disconnect and Retraction Mechanism. The propellant dump lines will be connected between the Agena fill couplings and the Agena service panel in the orbiter cargo bay (Fig. 3-16). The dump lines will be fixed mounted at the service panel and will have a quick disconnect coupling and a retraction mechanism at the Agena. These retraction mechanisms are similar to those presently on the launch pad but require some modifications. The retraction mechanisms are mounted to the Agena/payload support structure as shown by Fig. 3-16, which simplifies the Agena/payload mating and orbiter installation and also eliminates one interface with the orbiter.

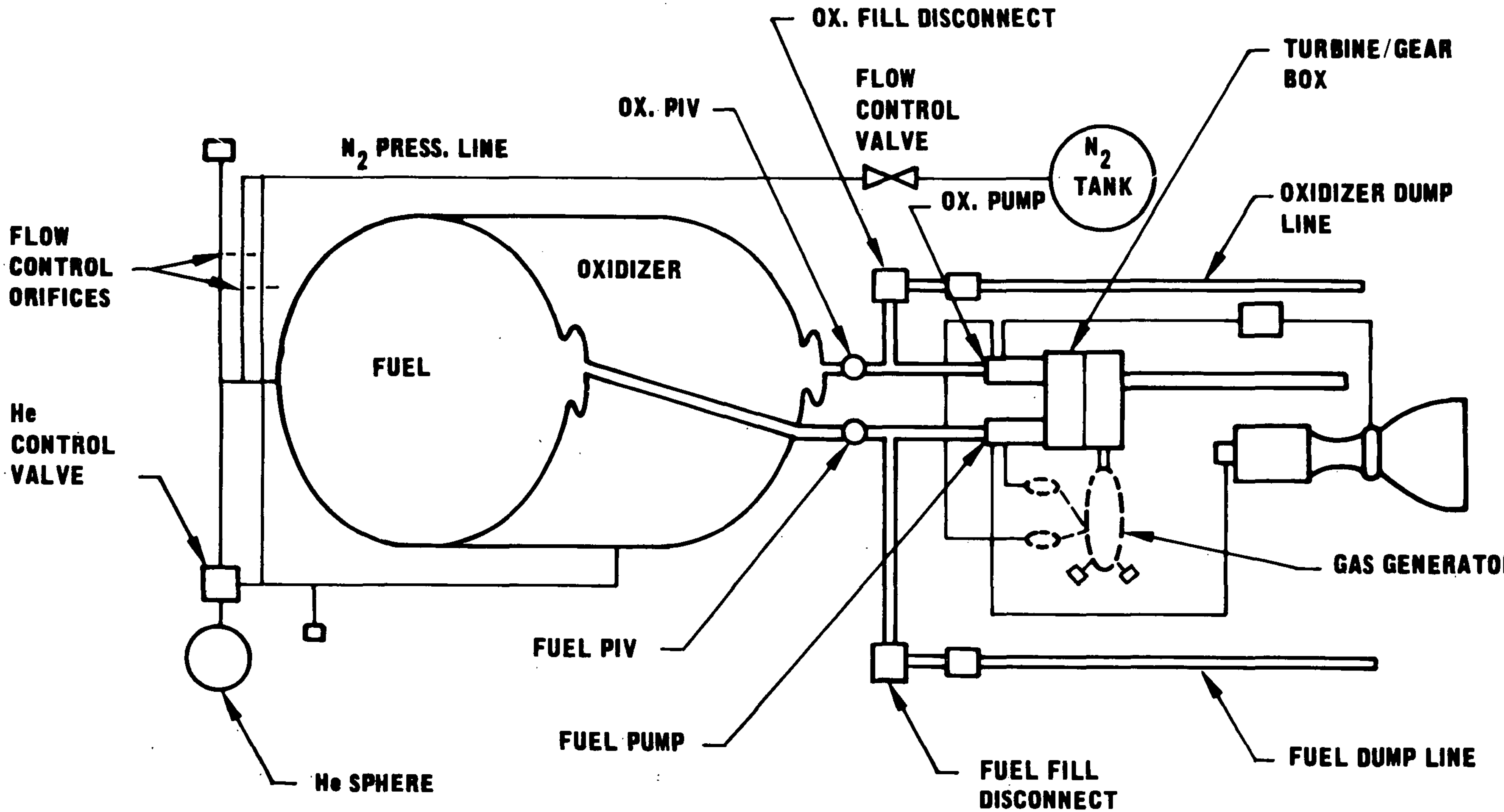

Fig. 3-15 Propulsion Schematic

The fill couplings for both IRFNA and UDMH service will require some modification. The existing oxidizer interface seal will be changed from Teflon to either Viton A or Nitroso rubber, and the UDMH interface seal will be changed to butyl rubber. This change is necessary to eliminate the presently stringent torquing requirements between the air-half (AH) ground-half (GH) Teflon interface seal and to eliminate a possible leak source. This change,along with tighter dimensional control over internal components,would eliminate the need for secondary torquing after mating.

A second change to the existing design would be a fixed poppet in the open position, so that when the GH is mated to the AH, the AH poppet would be directly opened and would remain opened for propellant dumping operations. This change would eliminate the need for a sliding poppet shaft and the chance of secondary leakage. In addition, it would eliminate the need for the nitrogen service port and subsequent nitrogen gas for its operation.

A third change would be to integrate the connect and disconnect mechanism into the retract mechanism so that the first few inches of retraction would affect the mechanical disconnect of the GH coupling.

Another design feature would be a manual override that would disengage the latching mechanism and allow a manual disconnect of the GH coupling. The manual override in one motion would disconnect the latching mechanism disengage the drive mechanism, and retract the coupling a minimum of 12 inches.

<u>Inner Support Tube.</u> This member would attach to the GH coupling and slide inside the outer support tube. The member would position and support the GH coupling as it is mated to the AH, and would provide the free end attachment for the electric driven ball bearing screw assembly.

<u>Outer Support Tube, Support Bracket, and Tube Brace Support.</u> These items provide the structural support for the inner support tube and would attach to the Agena support cradle.

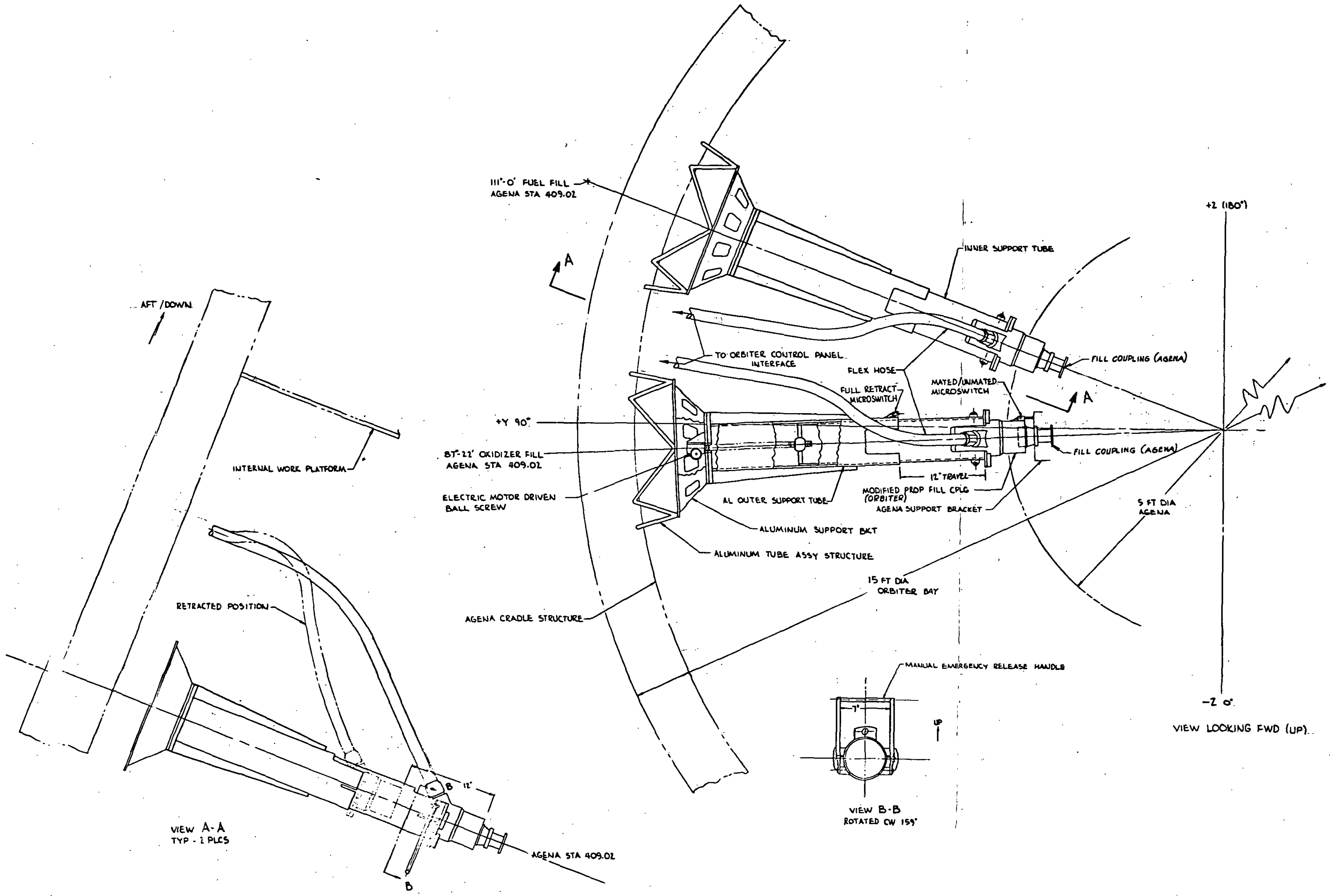

Fig. 3-16 Orbiter/Agena Tug Propellant Dump Umbilical System

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Drive Mechanism. A ball-bearing screw assembly shall be used to retract the coupling. The ball screw assembly will be driven by an electric motor and powered by the orbiter on-board electrical system.

3.3.1.3 Propulsion Ground Support Equipment. The Agena is designed to be in a vertical attitude for propellant loading. A view of a typical propellant-loading operation is shown in Fig. 3-17. In this view the Agena is mated to the booster with umbilical plumbing shown attached. At liftoff the plumbing connections are disconnected from the Agena and are pulled clear of the vehicle, along with the umbilical mast.

In the shuttle application, remote disconnect of the fuel and oxidizer lines at liftoff would not be at the Agena interface, but rather at the interface with the orbiter and the dump lines leading to the receiver tanks (Fig. 3-18). A second interconnect between the Agena and its cradle-mounted plumbing would be remotely disconnected at the time of orbital deployment. These disconnections will involve dry lines and present no problems from a design standpoint.

Since the Agena will be fueled before it is installed in the orbiter, the fill-line disconnects will not require flyaway type connectors and will not require remote actuation. Fueling will be with the vehicle in the vertical position. Following fill-line disconnect and verification of system integrity, the vehicle will be returned to a horizontal attitude for installation in the orbiter. Since normal tank vents will be submerged in this position, tank pressure must be controlled through temperature conditioning of the vehicle.

The existing Agena proplusion GSE is shown schematically in Fig. 3-19. With the exception of the vehicle disconnects the system is representative of the Agena space tug configuration. The propellant loading sequence begins by first loading about 10 percent of fuel, after which a hold is made to assure a liquid-tight system by monitoring the vapor sniffers located below the Agena. The next step is to load 10 percent of oxidizer and make a similar hold and monitor operation. Following this, the fuel and oxidizer tanks are filled from their respective propellant transfer units. The helium pressurization spheres are then loaded, although the pressurization sphere loading may be delayed for safety until the Agena is ready for installation into the shuttle,

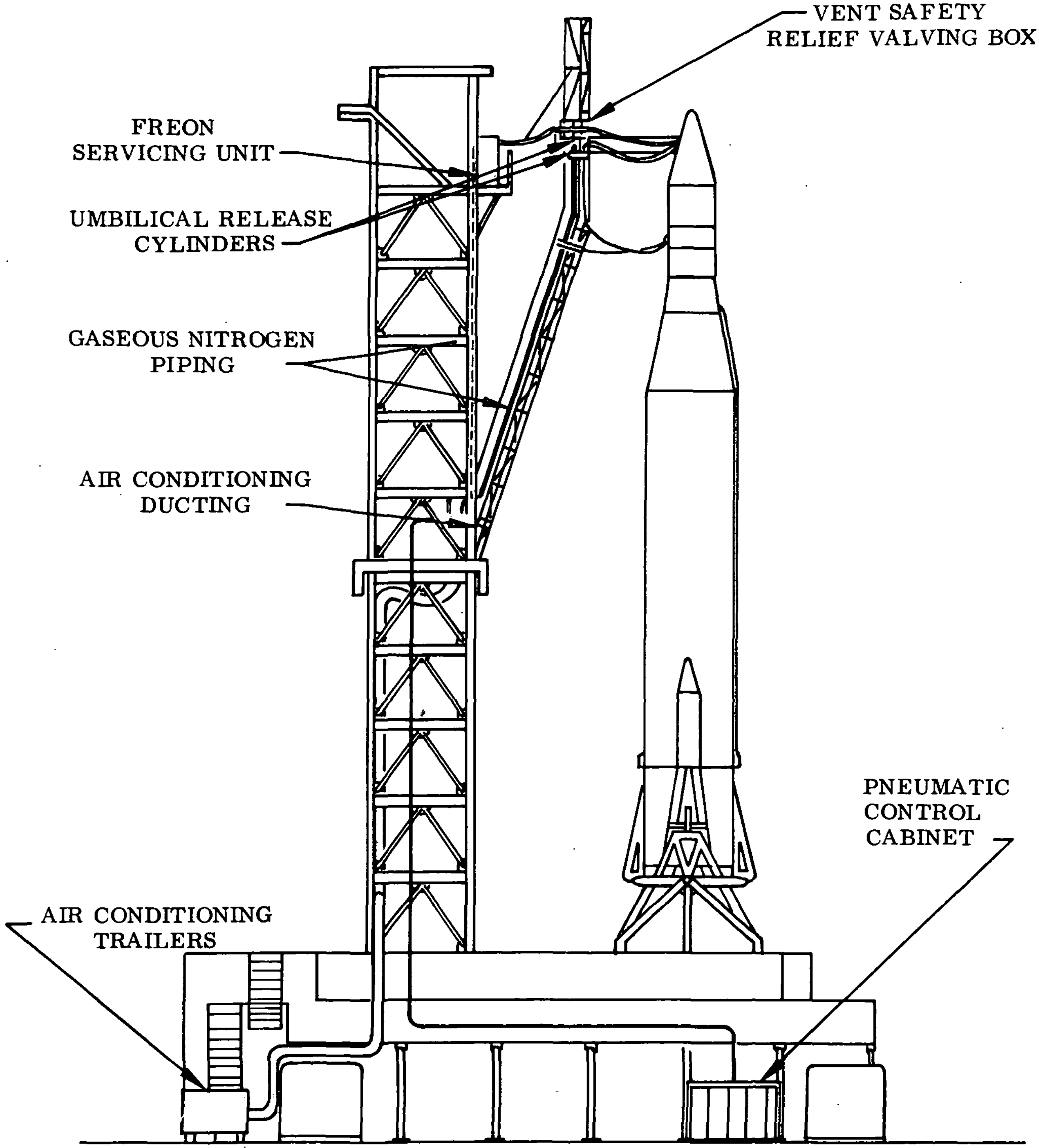

Fig. 3-17 Mast Equipment

- AGENA OPERATIONS AND DATA ARE HANDLED THRU SHUTTLE DATA BUS AND GROUND COMMUNICATIONS LINKS.
- OPTICAL PATH REQUIRED FOR AGENA ASCENT GUIDANCE AXIMUTH ALIGNMENT.
- DUMP SYSTEM IS FOR PRE-LIFTOFF SHUTTLE ABORT MODE. SYSTEM IS NORMALLY DRY.

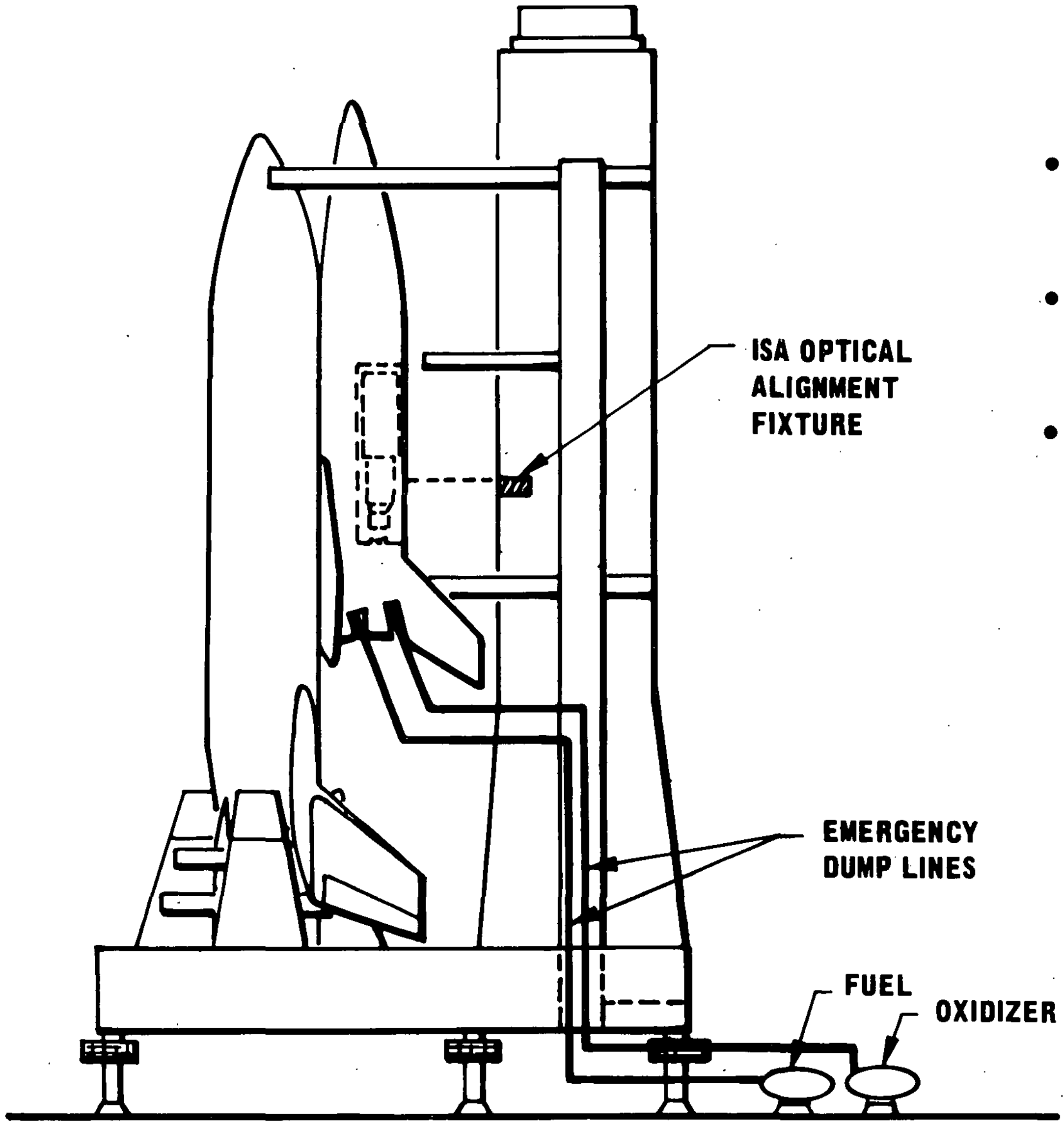

Fig. 3-18 Shuttle Pad Operations

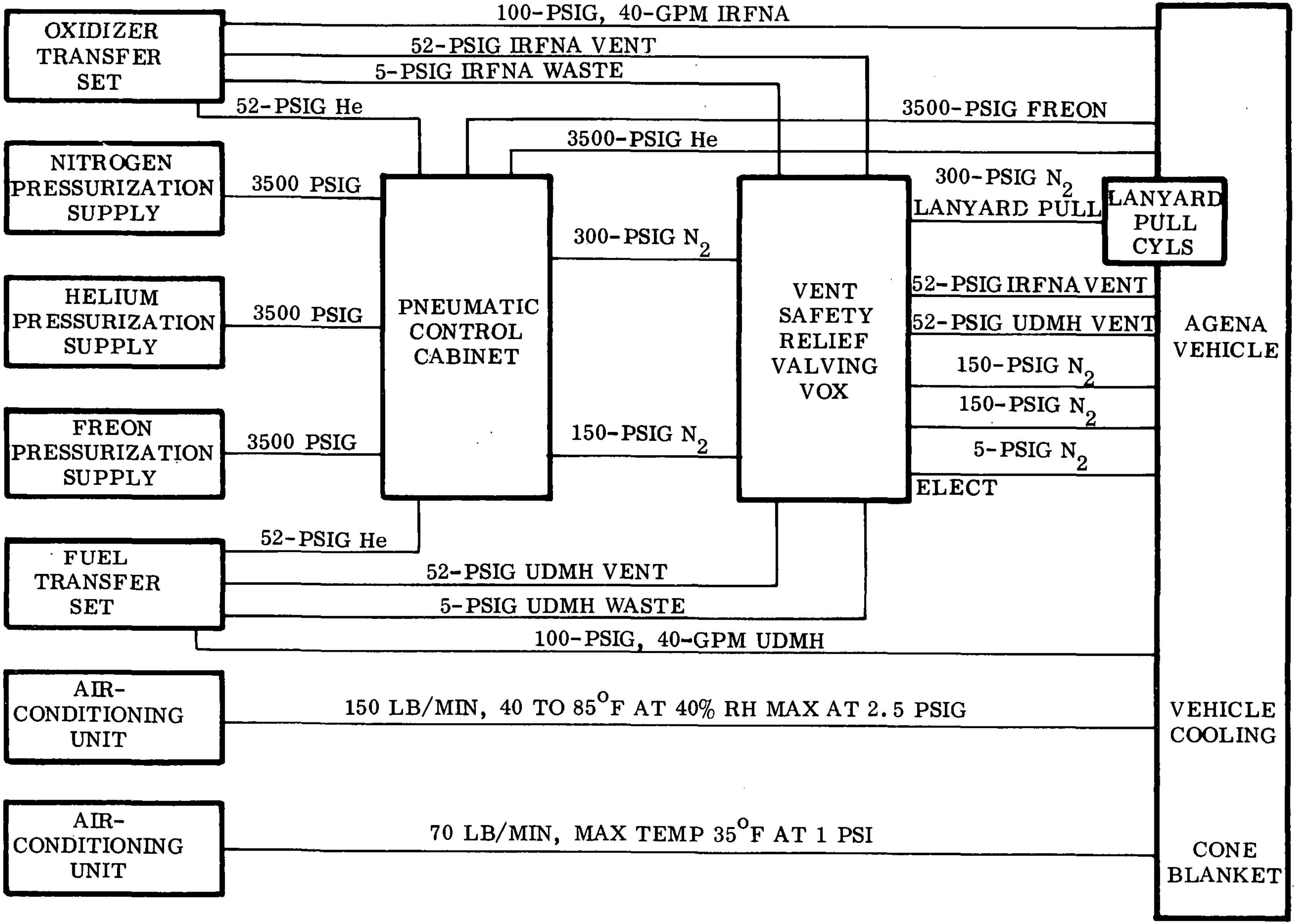

Fig. 3-19 Propulsion GSE Schematic (Typical)

since vehicle attitude is not important for gas loading. If the regulated pressurization system is used, the helium sphere may be partially pressurized following propellant loading and before separation of the tank vent and fill disconnects. The sphere can then be fully pressurized when the vehicle is ready for shuttle installation. Full-sphere pressurization just prior to Agena deployment from the shuttle can also be considered.

The propellant is recirculated in a propellant transfer unit for temperature conditioning. The required propellant loading weight is set on the unit scales, and this unit automatically stops pumping propellants to the Agena at the preset value. The weight of propellants required to fill the GSE plumbing is properly accounted for.

3.3.1.4 Engine Attitude. The best position for the engine while in horizontal position is for the gearbox to be in the 6 or 12 o'clock position (looking forward). In this position the oil level is below the oxidizer and fuel pump shaft seals, and no leakage can occur.

With the gearbox in the 3 o'clock position (looking forward) there is oil along the fuel pump shaft and seal when the pitch angle is from 10 deg nosedown to 90 deg noseup. There should be no significant problems in this attitude, although minor leakage can occur over a 3- to 4-week period. The fuel seal drain cavity line would have to be monitored.

If the vehicle is in the 9 o'clock position, the position currently selected for shuttle installation, there is a possibility of leakage through the oxidizer seal. One way to prevent this leakage is to apply pressure to the oxidizer pump lip seal whenever the seal is submerged. This can be done in a manner similar to the procedure currently used. The oxidizer pump seal drain cavity would have to be monitored.

3.3.2 Mission-Related Propulsion Design Requirements

The Agena propulsion system must fulfill the requirements of the three reference missions specified in the study guidelines:

a. Geosynchronous Mission – a two- or three-burn mission to transfer a payload to synchronous equatorial orbit.

b. Interplanetary Mission – a single-burn mission to place a Viking-type payload on a planetary transfer trajectory.

c. Low Earth Orbit Mission – a multiple-burn mission requiring return to the deployment orbit after 30 days.

The total time for that portion of the interplanetary mission involving the Agena space tug would be very short. The single-burn would require only about 4 minutes, preceded by a nominal prestart hold no more than one orbit rev (about 87 min) to reach the correct position for initiating the propulsion maneuver. The basic propulsion system, modified only for shuttle compatibility, would fulfill all of the requirements of this mission.

The synchronous equatorial mission is a short-duration mission spanning only 15 hours from deployment to completion of third burn. Agena three-burn capability, using solid-propellant start cans, has been demonstrated in prior missions and is a qualified system.

The synchronous equatorial orbit mission will have a short-duration second burn if a phasing orbit is used. Under conditions of low acceleration, short-duration burns can cause problems for subsequent burns in that the propellant sumps would not refill sufficiently to satisfy restart requirements. The reference mission acceleration data shown in Table 3-3 indicate acceleration levels of approximately 2.0g during this burn, so that unless the burn time is very short, adequate refilling can probably be expected.

The low earth orbit mission will impose propulsion requirements not within the capability of the basic ascent Agena system. The requirements for 30-day lifetime, multiple restart, and combined short-duration, low g burns indicate that modifications will be required in the engine, pressurization, and propellant management systems.

Table 3-3

TYPICAL REFERENCE MISSION ACCELERATIONS

Reference Mission and Event	Acceleration (g)		Nominal Burn Time (min)	Propellant Remaining at Shutdown (lb)
	Startup	Shutdown		
Synchronous Equatorial				
Burn 1	0.90	1.95	3.0	3834
Burn 2	1.95	2.00	0.1	3623
Burn 3	2.00	3.62	1.1	0
Interplanetary Mission				
Burn 1	0.82	2.84	4.2	0
Low Earth Orbit Mission				
Burn 1	0.41	0.47	1.6	8644
Burn 2	0.47	0.57	1.9	2623
(Deploy PL1)				
Burn 3	1.01	1.05	0.2	1983
Burn 4	1.05	1.08	0.1	1456
(29-Day Coast)				
Burn 5	1.09	1.14	0.3	718
Burn 6	1.14	1.21	0.2	0

3.3.2.1 Multistart Capability. The multiple-start requirements of the low earth orbit mission can be satisfied by incorporating the Gemini 8247 engine start system into the 8096 engine. A schematic of the Agena propulsion system with the multiple start engine incorporated is shown in Fig. 3-20.

In lieu of a pyrotechnic starter system, the multiple-start engine incorporates start tanks that are initially charged with propellants on the ground. The propellants in the oxidizer and fuel start system are contained in these tanks and in the lines between their respective upstream check valves and downstream gas generator solenoid valves. The remainder of the engine is dry.

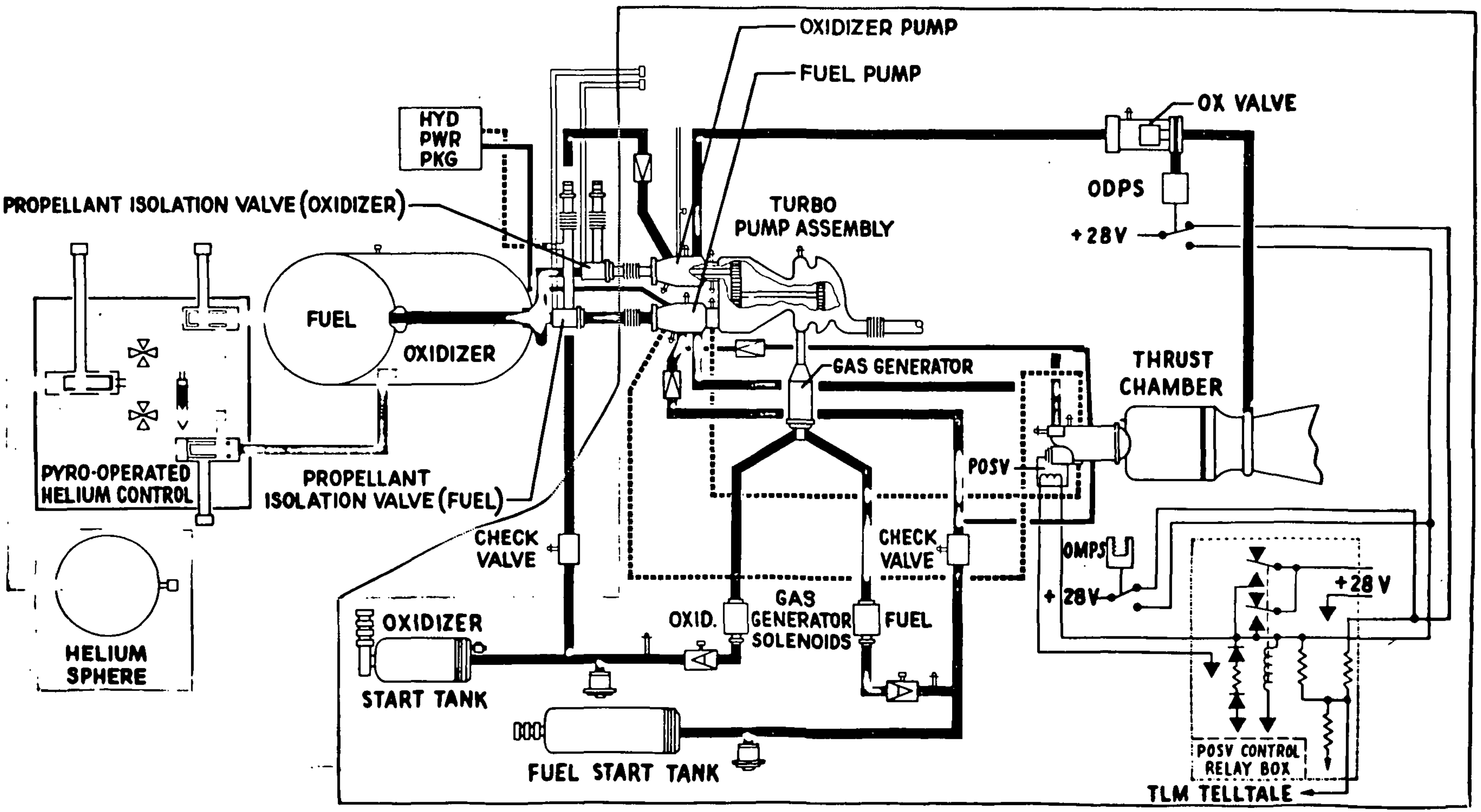

Fig. 3-20 Propulsion System Incorporating Multiple-Start Engine

At engine start the gas generator solenoid valves are opened and the pressurized start tank propellants initiate the engine start. During the engine steady-state operation, the start tanks are recharged with propellants; following shutdown they are ready for the subsequent engine start.

An electronic gate, shown schematically in Fig. 3-21 is part of the qualified multi-start system; it protects the engine against turbine overspeed if a valve or system failure occurs that would unload one or both of the engine pumps. With an unloaded pump, the start tanks will discharge into the gas generator, causing increased turbine speed. The electronic gate, sensing the overspeed, closes the gas generator solenoid valves. Further start attempts can be accomplished by proper electrical interface circuitry design.

The hardware required for the multiple-start engine consists of the start tanks, gas generator solenoid valves, check valves, and electronic overspeed control box.

The designs for the start tanks are available; however, the production capability of the manufacturers of the tanks, bellows, and fill valves must be reviewed. One or two new vendors may be required for the gas generator solenoid valves and the check valves. The electronic gate will require modifications to the existing baseline vehicle interface circuitry. Electrical and pressure test consoles (GSE) are not available, and fabrication of two sets is required for start tank loading and electrical interface checks on the ground while mated.

The start system is qualified for 38 days wet. The estimated 18 days on the ground and 30 days in space for the low earth orbit mission would exceed this slightly. A demonstration test may be required for requalifying for more than 38 days. The rest of the engine is qualified and no problem is envisioned.

For the 30-day orbit life requirement, the capability of the existing gearbox/lubrication system for multiburn application over 30 days of orbit life was evaluated; relevant data follow.

A lubricating kit was qualified and flown on early Agena flights (1960-62) to provide positive assurance of a filled gearcase at second start. Prior to this start, after the long coast of several weeks, a pyrotechnic valve was fired to inject 150 cc of lubricating oil into the gearcase from a pressurized cylinder. These flights were successful. However, subsequent test experience and further review of vapor pressure data indicate that the gearcase would not be dry after a 30-day exposure to a vacuum environment. In one vacuum exposure for 30 days, the gearbox lost approximately 1 cc of 150 cc total. In a 35-day vacuum exposure test, a 6-second firing was successfully completed without relubrication. In one test with only a film of oil, a 200-second firing of the 8096 turbine pump assembly was completed successfully. The MIL 7808B synthetic lubricating oil used in the gearbox has an allowable evaporation rate in a vacuum of 10^{-7} grams per cm^2 per second at $85^{o}F$. At this temperature the oil vapor pressure is approximately 1.5×10^{-6} torr. With this low vapor pressure and evaporation rate, calculation shows that the 150 cc of oil normally in the gearcase would be evaporated in 30 days. However, available test data show this is not true, and even in the worst case the present configuration gearbox, without the lubricating kit, should contain at least a film lube at the end of 30 days. Three Agena flights on a recent program have demonstrated 6-second second burns following 21-day coast periods without a relubrication kit. On the basis of the above information, the probability is high that the current design can accomplish this mission without the use of the relubrication kit. However, this condition will have to be demonstrated in a turbine pump assembly by a simulated mission life test, which will include tests with the relubrication kit as well as with only a film of lubricant in the gearbox. This would validate the present configuration gearbox lubricating capability for the low earth orbit mission, as well as possibly qualify the current design for use without the relubrication kit.

The allowable leakages of 8247 engine start system components are shown in Table 3-4. Engine weights with and without the multistart system are compared in Table 3-5.

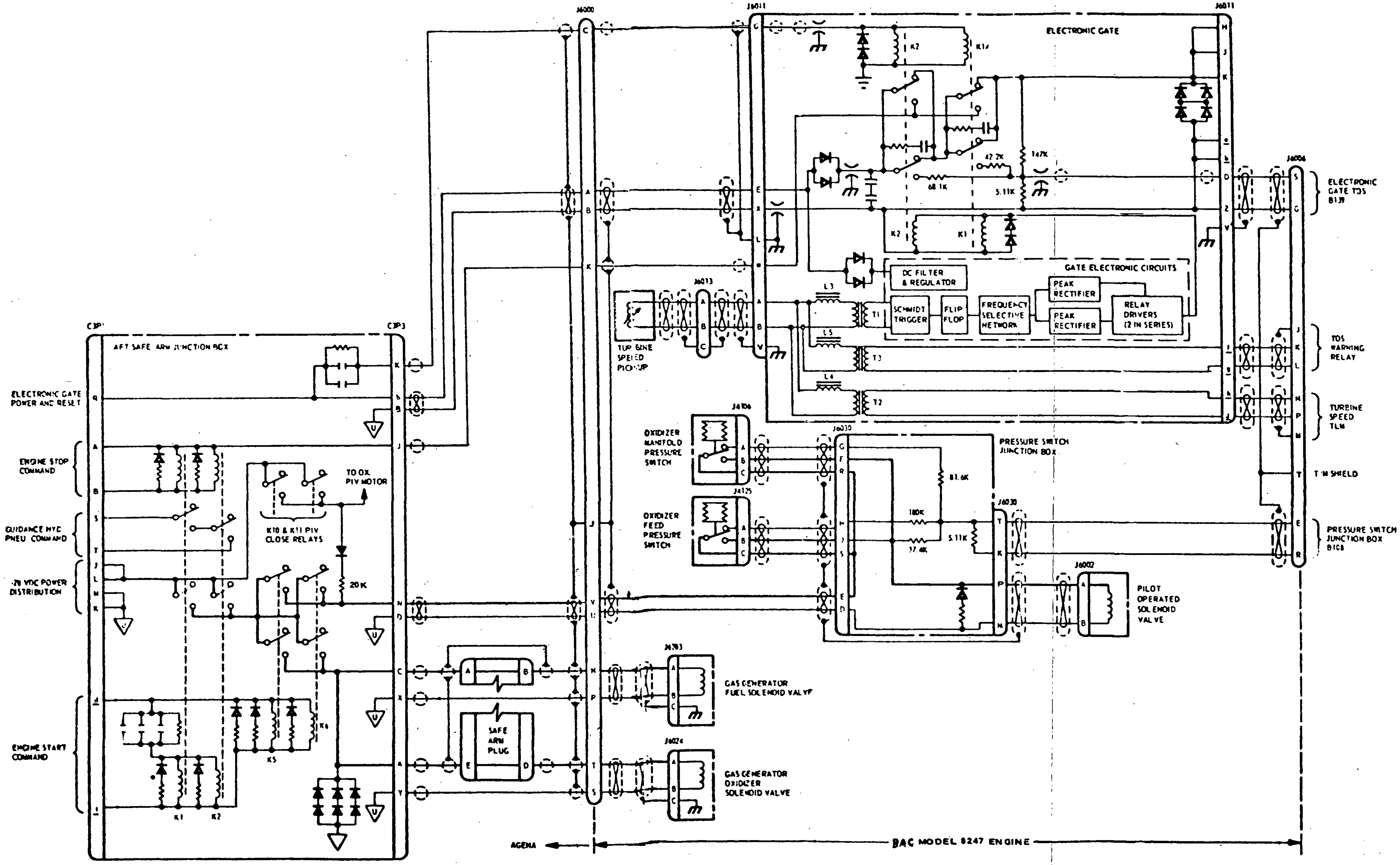

Fig. 3-21 Model 8247 Engine Electrical Interface

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Table 3-4

MODEL 8247 COMPONENT ALLOWABLE LEAKAGES

• START SYSTEM CHECK VALVES:	N_2 GAS AT	
(Fuel and oxidizer)	10–15 psig	950–990
Upstream poppet	1 SCCM	1 SCCM
Downstream poppet	1 SCCM	1 SCCM

If gas leakage occurs, a liquid leak check is performed; no liquid leakage is allowed.

• GAS GENERATOR SOLENOID VALVES (START SYSTEM):	N_2 GAS AT 1450 TO 1500
(Fuel and oxidizer)	
Outlet	6 SCCH when checked for 15 min
• PUMP AND MAIN VALVE LIQUID LEAKAGES – STATIC	
– Fuel Pump Primary and POSV at 70–75 psig	6.2 SCCM
– Oxidizer Pump Primary at 70–75 psig	5.0 SCCM

Table 3-5

COMPARATIVE ENGINE WEIGHTS

	8096	8096 engine with multiple start system
DRY	296	317
WET	307	329

• Basic 8096	Grains	1.08 lb each
	Igniters	0.58 lb each
• 8096 with multiple start system	Start Tank Propellant Weights	
	Fuel	3.05–GAS (N_2) 0.30
	Oxygen	0.97–GAS (N_2) 0.05
	Fuel and Oxygen trapped in start system lines	0.17 lb

• Engines with starting propellants, but no grease, oil, and no oxygen or fuel in pump discharge lines or pump housings

Basic 8096	299.3 lb
8096 w/multiple start system	321.5 lb

3.3.2.2 <u>Mission Performance Requirements.</u> Definitive performance requirements related to the Agena space tug missions cannot be determined at this time, because of the lack of specific payload definition. However, examination of the presently available mission models does indicate a number of missions with a heavy payload to a high-energy orbit. This is especially true for synchronous equatorial missions. The 8096 engine with a 45:1 expansion nozzle has a nominal specific impulse of 290.8 sec. At present an improvement program has been initiated that could increase the specific impulse up to 310 sec. This improvement program is being considered for other Agena programs and, if incorporated, will become standard equipment and should not be considered as a modification for the tug application.

This increase in performance will be accomplished by the following modifications to the propulsion system:

a. Substitute a -1 injector for the present injector
b. Use a higher density acid (HDA)
c. Increase the nozzle expansion ratio

These changes to the propulsion system will not significantly affect the Agena configuration, except for the nozzle extension. The use of high-density acid on flights not requiring restart has been demonstrated and its performance gain verified. Effects of higher vapor pressure on restart must be examined.

If a larger expansion ratio nozzle is used it will be necessary to relocate some of the structural members of the aft rack to accommodate the larger nozzle and thrust chamber. However, these modifications will become standard configuration and should not be considered as Agena modifications for the tug application.

Some performance degradation will result from the increase in propellant temperature from $60^{\circ}F$ to $75^{\circ}F$, because of the decrease in the propellant weight that can be loaded. The capacity decrease will be approximately 151 pounds for IRFNA-fueled system and 170 pounds for HDA-fueled systems. This performance loss is partially offset by an increase in specific impulse (approximately 0.6 sec) at the higher temperature. Use of HDA will also result in an increase in propellant residuals due to an increase in

bias allowance and to the higher density and vapor pressure. Preliminary estimates indicate a residuals weight of 72 pounds, approximately 24 pounds greater than with IRFNA.

3.3.2.3 Pressurization System. The orifice flow controlled blowdown type pressurization system for the current baseline Agena is acceptable for the interplanetary or synchronous equatorial missions, which have first-burn durations greater than 100 seconds. However, for the low earth orbit mission in which the first burn may be less than 100 seconds, the pyro-operated helium control valve would continue gas flow into the propellant tank following engine shutdown, resulting in overpressurization of the propellant tanks. A motor-operated valve (used on SO1A Agenas) or a regulated system with relief valves (used on the Agena B vehicles) would be capable of preventing overpressurization of the tanks.

The motor-operated valve would open at 1.5 seconds following MPR of first burn. The pressure characteristics would then be normal. However, for a first burn duration of less than 100 seconds, the sphere and tank pressures would remain essentially constant following engine shutdown and valve closing. The valve may not necessarily be opened for second burn if second burn is of short duration. When the valve is opened for a subsequent burn it can be left open if the accumulated engine burn time exceeds approximately 100 seconds. The motor-operated valve provides considerable flexibility and would satisfy the requirements of presently envisioned Agena space tug missions. The motor-operated valve must be sequenced (modified electrical interface) and does not have the automatic regulation control of the regulated system.

A schematic of the regulated pressurization system used for Agena B flights is shown in Fig. 3-22. This system is considered because of its compatibility with the emergency dump requirements. The vent circuits consist of fuel and oxidizer vent relief valves. The fuel vent valve provides pressure relief for the fuel tank. The oxidizer vent valve, in addition to providing pressure relief for the oxidizer tank, senses fuel tank pressure and protects the tank bulkhead against reverse pressure by venting the oxidizer tank.

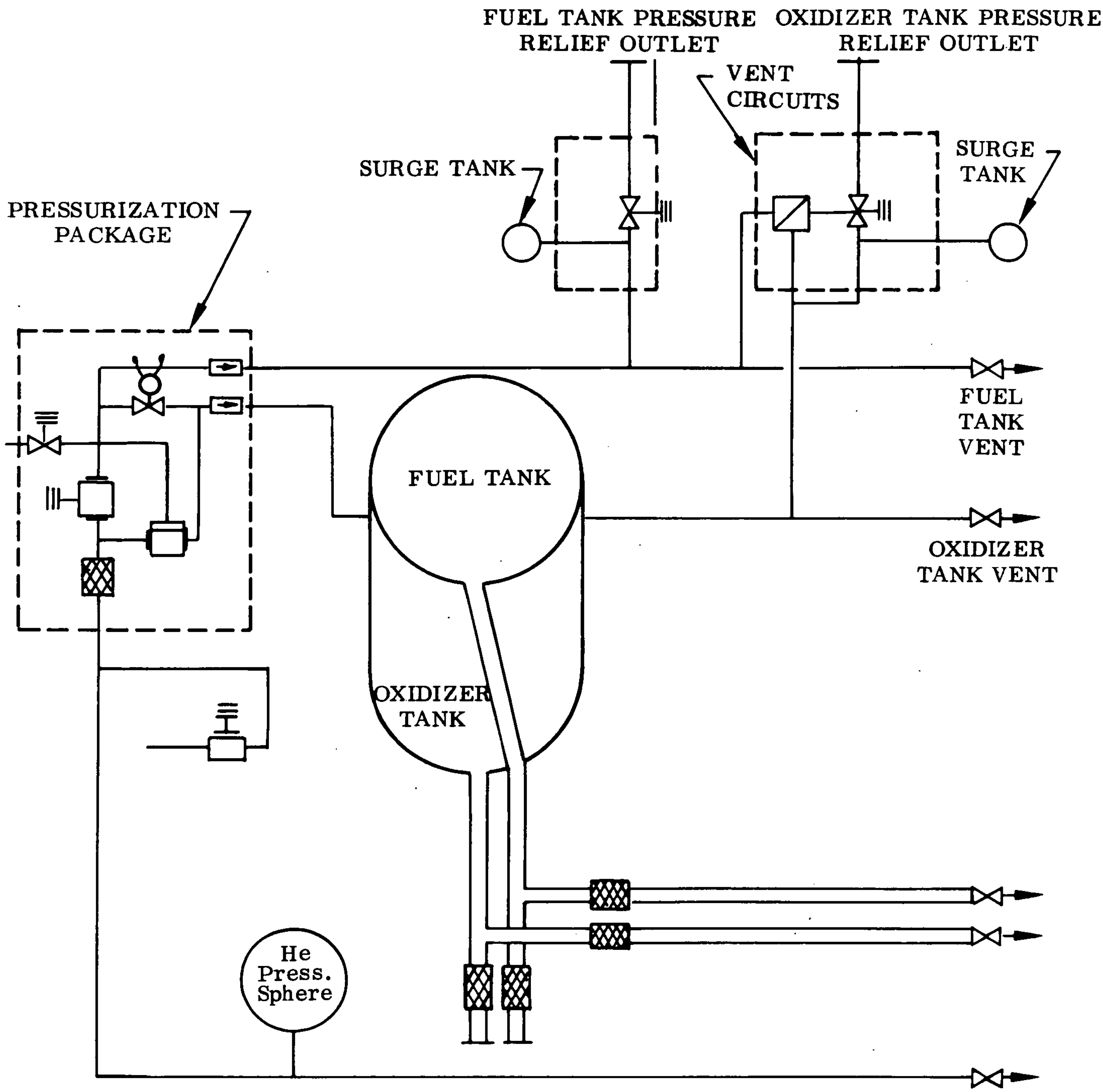


Fig. 3-22 Regulated Pressurization System Schematic

3.3.2.4 Propellant Management System. For the low earth orbit missions the combination of low-acceleration and short-duration burns with low propellant quantities remaining in the tanks will probably result in insufficient propellant sump refilling if the propellants are disoriented forward prior to restart. This problem can be overcome by resizing the sump screens or incorporating passive propellant retention baffles.

Assuming full shuttle orbit delivery capability of 65,000 pounds, it is possible to conceive Agena space tug missions with payloads in the 40- to 50,000-pound range. Acceleration levels for such missions would range from 0.25g to 0.04g and could impose propellant management problems considerably more severe than for the reference missions considered in this study. Therefore, to ensure maximum mission flexibility for the Agena space tug, the propellant-retention system redesign should be deferred until the complete spectrum of missions and payloads can be better defined.

3.3.3 Integrated Propulsion System

A standardized Agena propulsion system design capable of satisfying all conditions, based on shuttle compatibility and mission requirements, is the obvious goal to be pursued. From the analyses conducted in this study it appears the goal can be satisfied, although use of kits such as the relubrication kit to satisfy certain infrequent mission requirements may prove to be more desirable in preserving basic system simplicity and reliability. From this standpoint, the following summary of propulsion modifications offers the most promising solution.

Use of existing propellant fill lines for abort dumping of Agena propellant has the least impact on the system and satisfies the goals established for dumping time. Tank repressurization after dumping is recommended, with design modifications incorporated to permit use of the high-pressure nitrogen source for the attitude control thrusters.

As much as possible of the existing Agena GSE should be used; however, some changes related to the scheduling of propellant loading in advance of orbiter mating and to plumbing and pressurization system modifications will be required.

Incorporation of the multiple restart engine and associated pressurization and propellant management modifications is favored for all missions. This system will provide maximum mission flexibility by eliminating potential problems related to the number and duration of burns. A regulated pressurization system is probably best suited to the varied mission requirements. Propellant retention-system modifications should be common, but cannot be specifically designed at this time.

3.4 GUIDANCE AND ATTITUDE CONTROL SUBSYSTEM

A design study was performed to establish a baseline guidance and control system for the Agena space tug vehicle. In this application, the Agena will be carried in the shuttle cargo bay and injected into a 100 nm circular orbit. The Agena will then be used as a tug to ferry payloads to and from other orbits. The specific design missions to be accomplished by the Agena follow:

a. Synchronous Equatorial
b. Planetary Probe
c. Long-Duration Multi-Orbit (Dual burn to 600 nm circular sun synchronous orbit, separate a payload, dual burn to 400 nm circular, provide a stable platform for 30 days, dual burn down to 100 nm circular)

Design objectives for selecting the guidance and control system included maximum utilization of existing, flight-proven hardware, and minimizing the requirements imposed on the shuttle interface. In accordance with these ground rules, primary emphasis was placed on the existing ascent guidance system (AGS) used successfully for ascent guidance, and the dual attitude control system (DACS) used for long-term, on-orbit missions.

3.4.1 Ascent Guidance System

The inertial AGS, which was developed for the ascent Agena vehicle, has sufficient capability and flexibility to be used as the guidance system for the Agena space tug application. Although some hardware modifications will be required and additional equipment will be needed to augment its capability and to provide compatibility with the shuttle system.

The AGS consists of an inertial sensor assembly (ISA), a guidance computer (GC), flight control electronics (FCE), hydraulic actuators for thrust vector control, and a pneumatic system for attitude control during coast phases and on-orbit attitude stabilization.

3.4.1.1 Ascent Guidance System Hardware. The AGS system is a strapdown inertial guidance system that has been successfully flown on an Air Force mission. A basic block diagram of the system is shown in Fig. 3-23. The ISA is a three-gyro, three-accelerometer, nonredundant package with an accelerometer quantization of 0.27 ft/sec and dual gyro quantizations of 6.3 arc sec and 55.4 arc sec. The characteristics of the computer and sensor assembly are summarized in Tables 3-6 and 3-7. Twenty-one of the output discretes can be safed by hardware circuitry; these are presently used for pyro functions. The guidance computer provides steering signals to a flight control electronics assembly to control two hydraulic engine actuators and six cold-gas pneumatic thrust valves. The signals to the actuators are analog, and those to the thrusters pulsewidth modulated. For present missions, pulsewidth-modulated signals are also supplied to the booster stages. The computer also generates all necessary vehicle discretes, and formats output for a PCM telemetry system.

3.4.1.2 AGS Software (Flight Program). The AGS flight program is stored in the airborne computer during flight. It includes functions required during the countdown as well as those required during flight. A functional block diagram of the flight program is shown in Fig. 3-24.

The functions utilized during countdown permit automated vehicle checks, on command, to verify the health of the vehicle. The ability to dump the contents of memory to a ground computer so that it may be verified on a bit-by-bit basis by ground support software is included. In addition to the test function, a flight initialization routine aligns the strapdown system. This is the software equivalent of platform leveling and azimuth orientation determination. Provisions are made to input an optically determined azimuth correction during sensor alignment to reduce the initial azimuth uncertainty from 30 arc minutes to approximately 3 arc minutes.

The flight functions include the navigation and control processes necessary to place the vehicle into the desired orbits with the desired orientations. This information is transmitted to the program via the use of target and constants tapes utilizing a single flight program. Only minor modification to the existing software would be required to support the specified space tug missions.

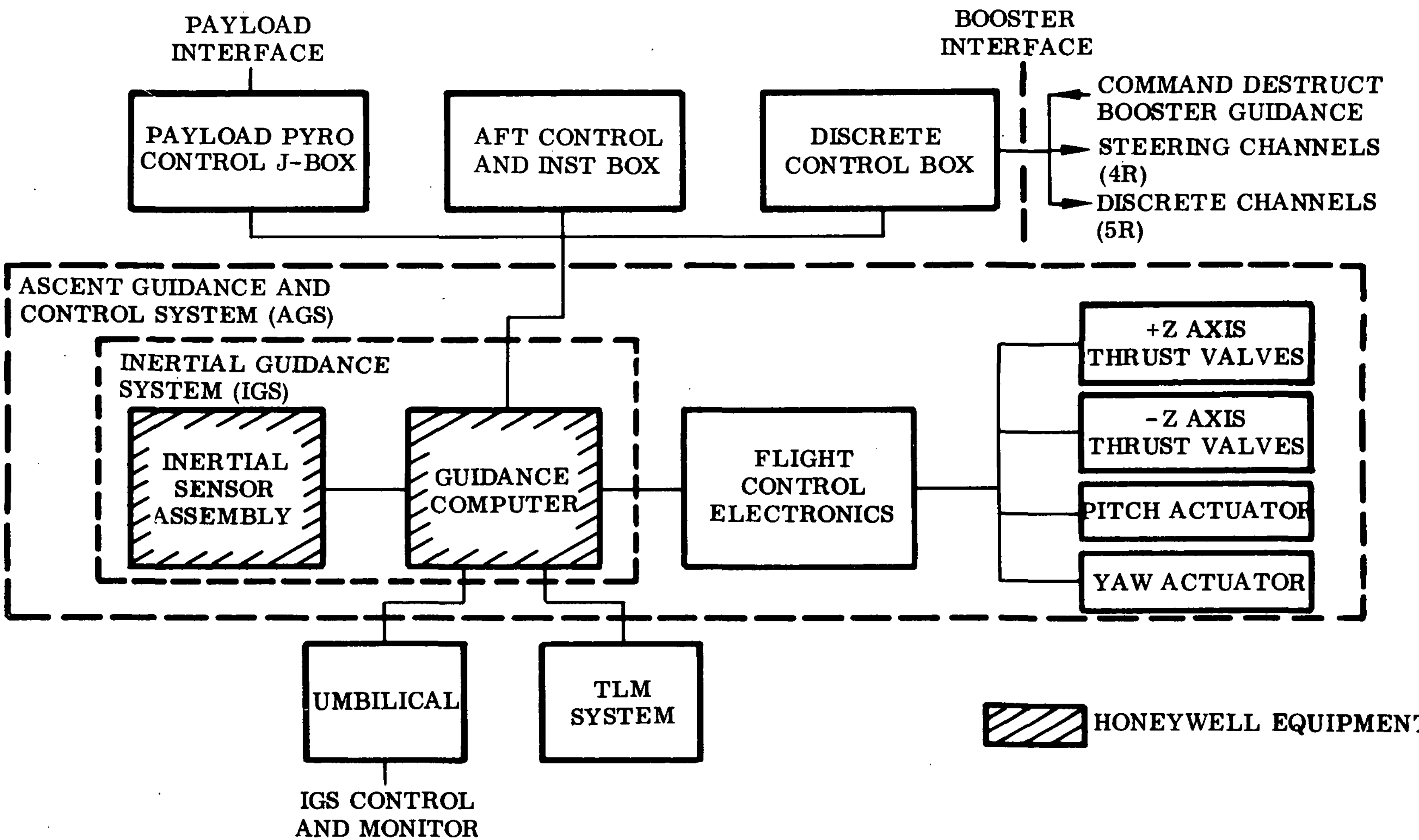


Fig. 3-23 Ascent Guidance System Block Diagram

Table 3-6

HONEYWELL 501 GUIDANCE COMPUTER CHARACTERISTICS

• Memory Capacity	8,192 Words
• Word Length	20 Bits
• Memory Cycle Time	2 Microseconds
• Add Time	4 Microseconds
• Multiply Time	24 Microseconds
• Index Registers	4
• Instructions	63 Instructions
• Arithmetic Type	Parallel, Fixed Point, Two's Complement
• Input	Interrupts: 9 + 3 Programmed Interrupts 12 Sensed Discrete Inputs Which May be Sampled by Software A/D Conversion: 2 Channels
• Outputs	Pulses (100-millisecond duration) Discretes: 64 Variable (10 milliseconds – 4,000-second duration) Discretes: 64 Digital/Analog Conversion: 3 Channels Telemetry, Parallel In/Serial Out: 24 Bits Simulated Torquing (gyros)
• Weight	48 Pounds
• Power Requirements	150 Watts (Maximum 50% Read/50% Write) 127 Watts (Maximum Standby)
• Size	12.2 x 16.85 x 9.75 Inches

Table 3-7

INERTIAL SENSOR ASSEMBLY CHARACTERISTICS

SENSOR COMPLEMENT

Gyros

- Three Honeywell GG334A-8 Gyros
- Pulsed Rebalanced
- Single Degree of Freedom
- Rate Range: $\pm 25^{\circ}$/sec
- Granularity, Low Range: 6.2947 sec
  High Range: 56.3576 sec

Accelerometers

- Three Honeywell GG177-P5 Accelerometers
- Pulsed Rebalanced
- Acceleration Range: ±15 g
- Acceleration Threshold: 1×10^{-5} g
- Scale Factor Resolution: 0.27 ±1% Foot per Second
- Pulse Rate: 1,800 Pulses per Second

PHYSICAL CHARACTERISTICS

- Weight: 38 Pounds
- Power: 125 Watts
- Size: 12 x 16.5 x 5 Inches

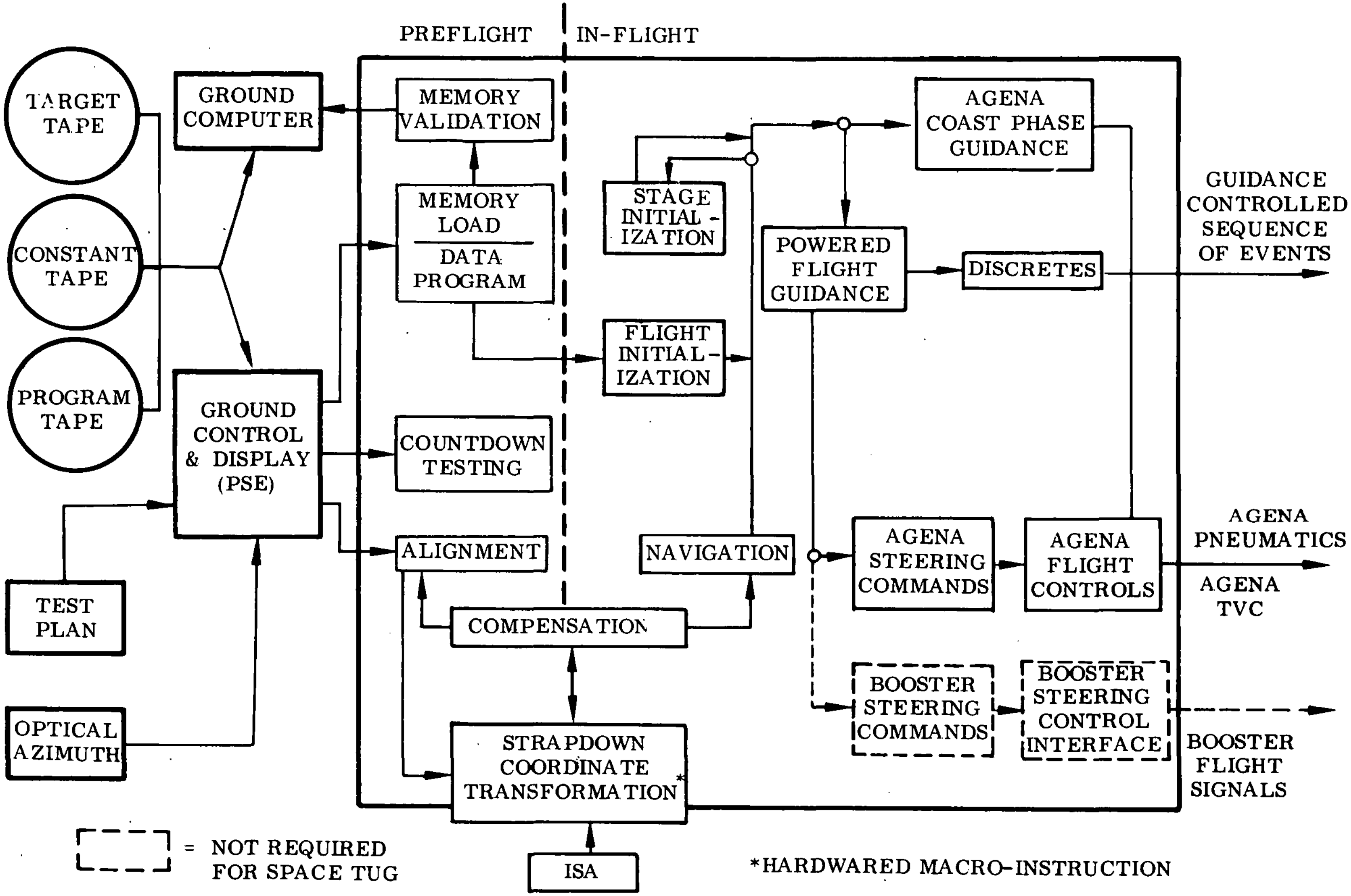


Fig. 3-24 Flight Program Functions

The Flight Program accomplishes control through the use of six cycles:

a. Strapdown Algorithm. A hardwired macro-instruction that converts the ISA sensed body acceleration and rates into an inertial reference frame through the use of a body to inertial direction cosine matrix and an inertial velocity change vector.

b. Instrument Compensation. A software routine that corrects the inertial reference established by the strapdown algorithm to account for measured instrumentation errors determined from a series of calibrations.

c. Navigation and Guidance. A routine that determines the vehicle inertial position and velocity and computes the conditions necessary to satisfactorily attain the desired terminal conditions. The conditions computed include the desired vehicle attitude history and burn durations.

d. Steering. Converts the instantaneous difference between the vehicle attitude and the desired attitude into a commanded vehicle attitude rate.

e. Flight Controls. Converts the difference between the current vehicle attitude and rate and the desired attitude and rate into commands to the engine actuators and pneumatic valves.

f. Discretes. This routine controls the initiation and termination of engine burns and such other housekeeping functions as tank pressurization, propellant isolation, and tape recorder on and off. Sixty-four computer-issued discretes are available and may be issued on one of five criteria: (1) time from a specified event; (2) angular momentum; (3) radius; (4) range angle; and (5) energy. Twenty-one of these discretes can be safed by a hardware switch, so that they will not be issued even if commanded by the computer. These are used for pyro functions.

As indicated in Fig. 3-24, the capability for booster steering now included in the AGS program may be deleted for space tug applications.

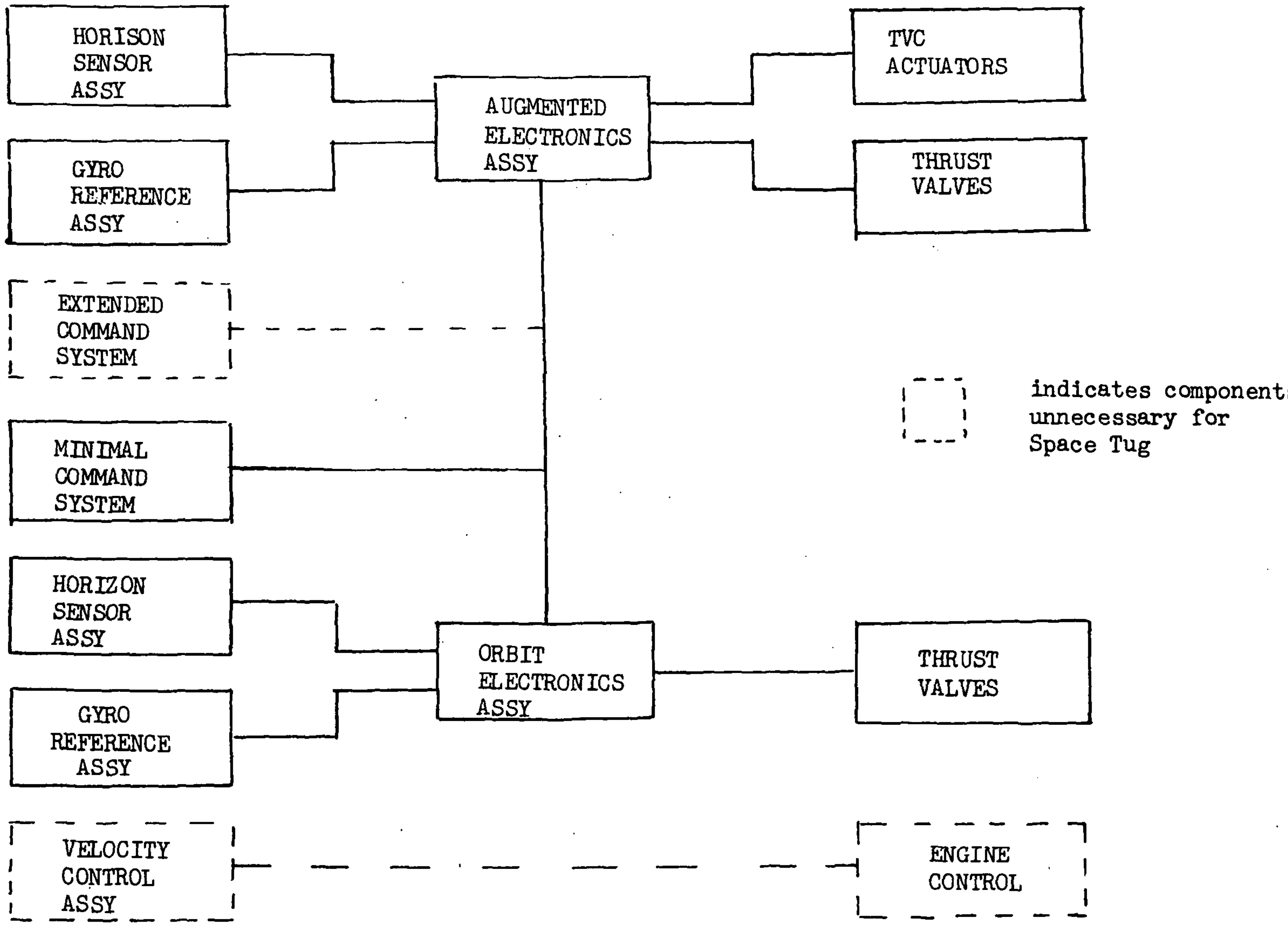
3.4.2 AGS Application to Space Tug

3.4.2.1 Mission Requirements. The AGS system was designed as an ascent system. However, two of the three space tug design missions (the synchronous equatorial mission and the planetary probe) are essentially ascent missions, and the AGS capability is therefore directly applicable. For these missions it is necessary to design only the appropriate Agena/shuttle interface.

The AGS system could also be used for the long-duration, multi-orbit design mission, particularly to control the powered-flight and short-coast phases of the mission. However, added redundancy would be required to meet the guaranteed lifetime requirements. Also, the AGS power requirements become extremely high for 30 days of operation. It is therefore appropriate for this mission to add another system with the primary function of providing attitude control over long coast periods. In addition, a limited command system would be required to turn the AGS system on and off, provide updated ephemeris data, etc.

One method would be to include the complete DACS in its present form to augment the AGS system. The DACS (Fig. 3-25 and 3-26) consists of a velocity control assembly, sequence timer, gyro reference assembly, augmented electronic assembly, and horizon sensor assembly. In this case, control of the vehicle will be transferred from the AGS to the DACS system after the spacecraft orbit has been established. The guidance computer and the inertial sensor assembly can then be turned off until just before the final orbit maneuvers. This combined system is shown schematically in Fig. 3-27; however, the velocity control assembly and the sequence timer have been removed from the DACS, since they are not needed for this application.

Another method would be to add only the horizon sensor unit from the DACS system. Output from the horizon sensor would then be fed to the guidance computer, together with the output from the inertial sensor assembly. This would represent a saving in control system weight of approximately 100 pounds, but it has the disadvantage that the inertial sensor assembly and the guidance computer must run continuously for 30 days. Also, since the power consumption will be high, the additional power supply weight may offset any gain from eliminating the DACS.



Max. power 164 watts (70 watts with dotted elements deleted)
Total wt. 273 lb. (153 lb with dotted elements deleted)

Fig. 3-25 Dual Attitude Control System Block Diagram

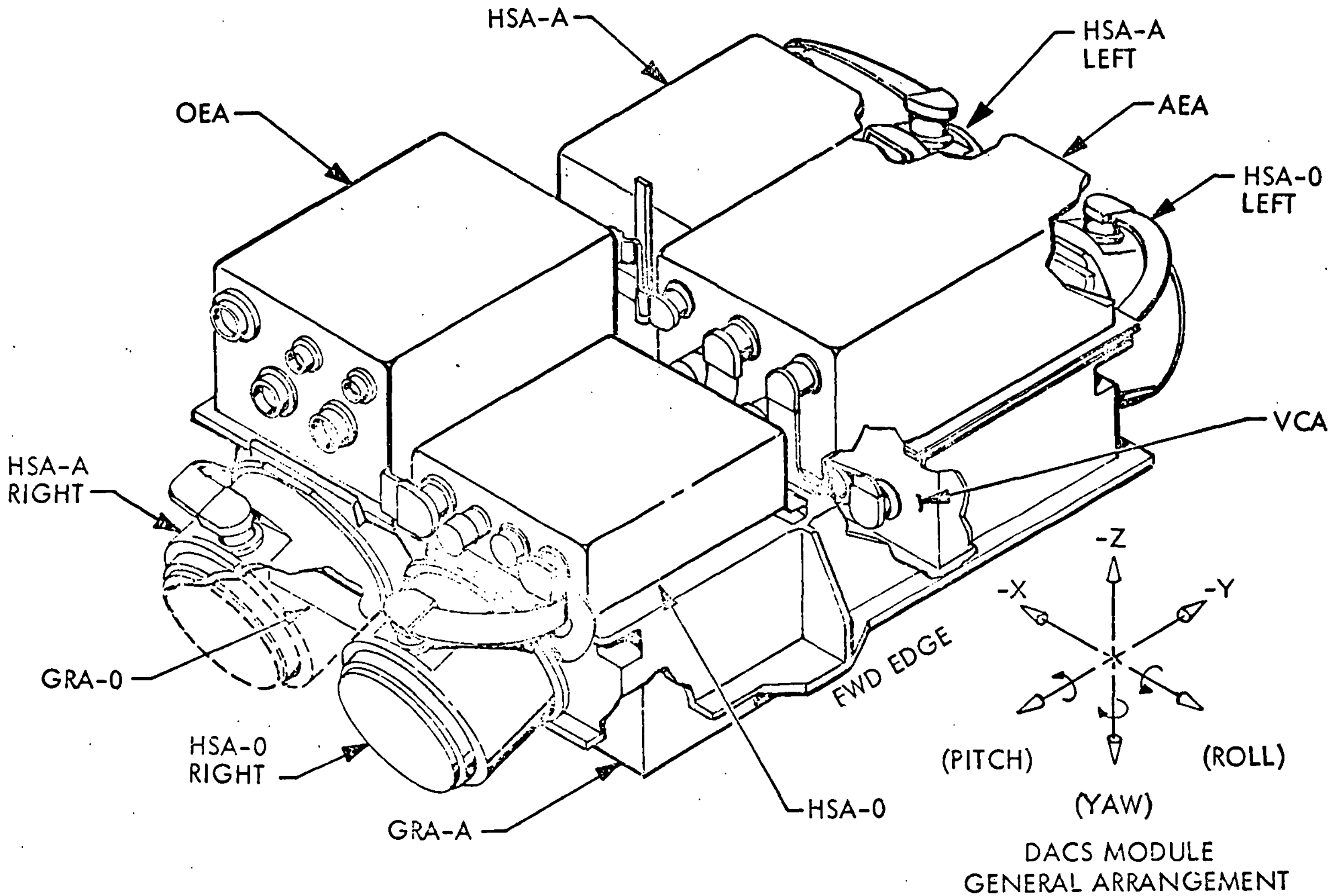


Fig. 3-26 Dual Attitude Control System

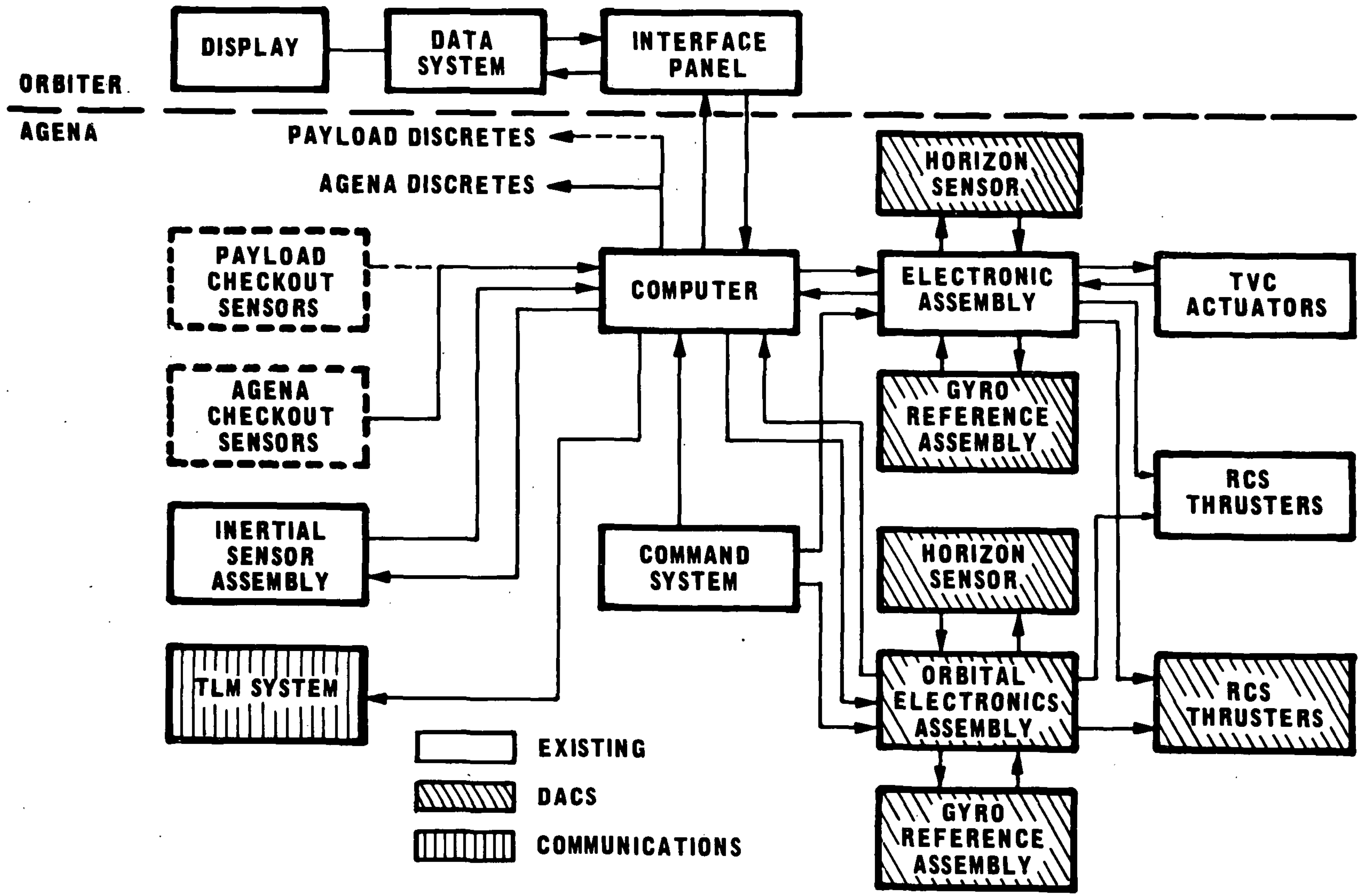


Fig. 3-27 Agena Space Tug Guidance and Attitude Control System

A third method would be to use only the horizon sensor unit for attitude control and feed the output directly to the flight control electronics. This will require additional electronic equipment between the horizon sensor assembly and the electronics assembly, but it has the advantage that the main guidance components can be turned off for long orbit stay times, which will significantly reduce power requirements and increase the reliability of the guidance system.

Lockheed is presently flying the DACS on Air Force missions requiring on-orbit lifetimes of 30 to 60 days. It has been evaluated and found suitable for use on future missions of considerably longer duration. It is basically a redundant form to the Standard Agena system, which has flown on more than 300 vehicles, including all of the NASA Agenas. For the space tug configuration, the velocity control assembly and extended command system, which is a highly secure and complex system, may be deleted. Doing this results in a weight savings of 153 pounds and a saving in power of 70 watts. This is indicated in Fig. 3-25.

Combining DACS with AGS (parts list in Table 3-8) will enable lifetime requirements for the 30-day mission to be met. The high-accuracy AGS system would be used during powered flight and short coasts. During the long on-orbit periods of a mission, AGS would be shut down to conserve power, and the DACS system would be used. Several components, such as thrust valves, are common to both systems. Therefore, the total weight and power would be less than the figure obtained by simply adding the weights and powers for each system.

The only addition necessary for shuttle compatibility is a connection to an Agena/payload service panel in the orbiter. Some components, such as the telemetry system and electronics assembly, would have to be modified to be made compatible with both systems.

While the combined AGS/DACS system will meet the objectives of the space tug mission with existing hardware, new computers, and instrument packages combining low weight, low power, and high reliability are currently in various stages of design or fabrication. Utilization of a fourth-generation computer in place of the current AGS computer, for example, could provide a single system that provides the same capability as the combined AGS/DACS system, with much reduced power requirements and weight.

Table 3-8

GUIDANCE SYSTEM LMSC PART NUMBERS

AGS:	
Inertial Sensor Assembly	1460976
Guidance Computer	1460977
DACS:	
Gyro Reference Assembly	1464439
Horizon Sensor	1464440
Orbital Electronics Assembly	1387591
Augmented Electronics Assembly	1387593
Telemetry System	1462182
Command System (GFE)	
Extended Command System	7638786*
Minimum Command System	7638725*
Readout Decoder	7642204*

*GFE Drawing Numbers

3.4.2.2 Integrated Test Program. The Integrated Test Program (ITP) is presently used with AGS for complete vehicle checkout prior to launch. It is used for end-to-end tests, subsystems checkout, and troubleshooting. With some modification, it or a similar program could be used for a final status check before the Agena is separated from the orbiter and for periodic health checks on orbit. The ITP would have to be integrated with the flight program for this usage. That would not represent a major change, since the flight program already contains portions of the ITP for use in count-down testing.

The ITP is discretely automated, rather than being a single automatic test sequence. There are several reasons for this:

a. It is intended not only for end-to-end tests but also for detailed subsystem checks. Changes in test area setup or vehicle orientation are often desirable between tests.

b. It is considered desirable to do a preliminary evaluation of the data from one test before proceeding to the next.

c. It is also used for troubleshooting.

The ITP contains 114 tests. Of these, 86 merely command discretes on or off. Ten of the 28 true tests have capability for specifying test parameters (e.g., test duration, gyro torquing rates) via typewriter at time of test. A data tape, similar to the flight program constants tape, provides capability to change simulated flight sequences, flight control parameters, geographic constants, and ISA compensation parameters without altering the basic program.

Figure 3-28 is an example of the various levels of testing possible with the ITP. Inputs can be supplied to the pneumatic flight control system at four points. At the simplest level, a voltage is applied directly to the thruster solenoid. Commands are available that will turn on only one specified thruster for a specified length of time or that will apply a timed sequence of pulses to each thruster in turn. At the next higher level, numbers may be loaded directly into those computer memory cells wherein body rates are stored. These rates are then processed through the flight control software, causing the thrusters to fire in a predictable manner. To provide a more complete end-to-end check, it is possible to apply torquing commands to the gyros. The gyro responses are again processed through the flight control software, causing predictable responses. Finally, as an end-to-end polarity check, the vehicle is physically rotated through small angles about each axis. A special software routine facilitates easy monitoring and interpretation of the pneumatic thruster responses.

To support system checkout and to monitor the vehicle performance and safety during flight, a number of diagnostic sensors will be included. Sensor output will be checked by the guidance computer and the information will be stored so that the time history of a given parameter can be reconstructed if desirable. A preliminary list of sensors follows:

Fuel tank pressure	Thrust chamber pressure
Oxidizer tank pressure	Turbine speed counter
Fuel tank/oxidizer tank differential pressure	N_2 gas valve temperature

PNEUMATIC FLIGHT CONTROL TESTING

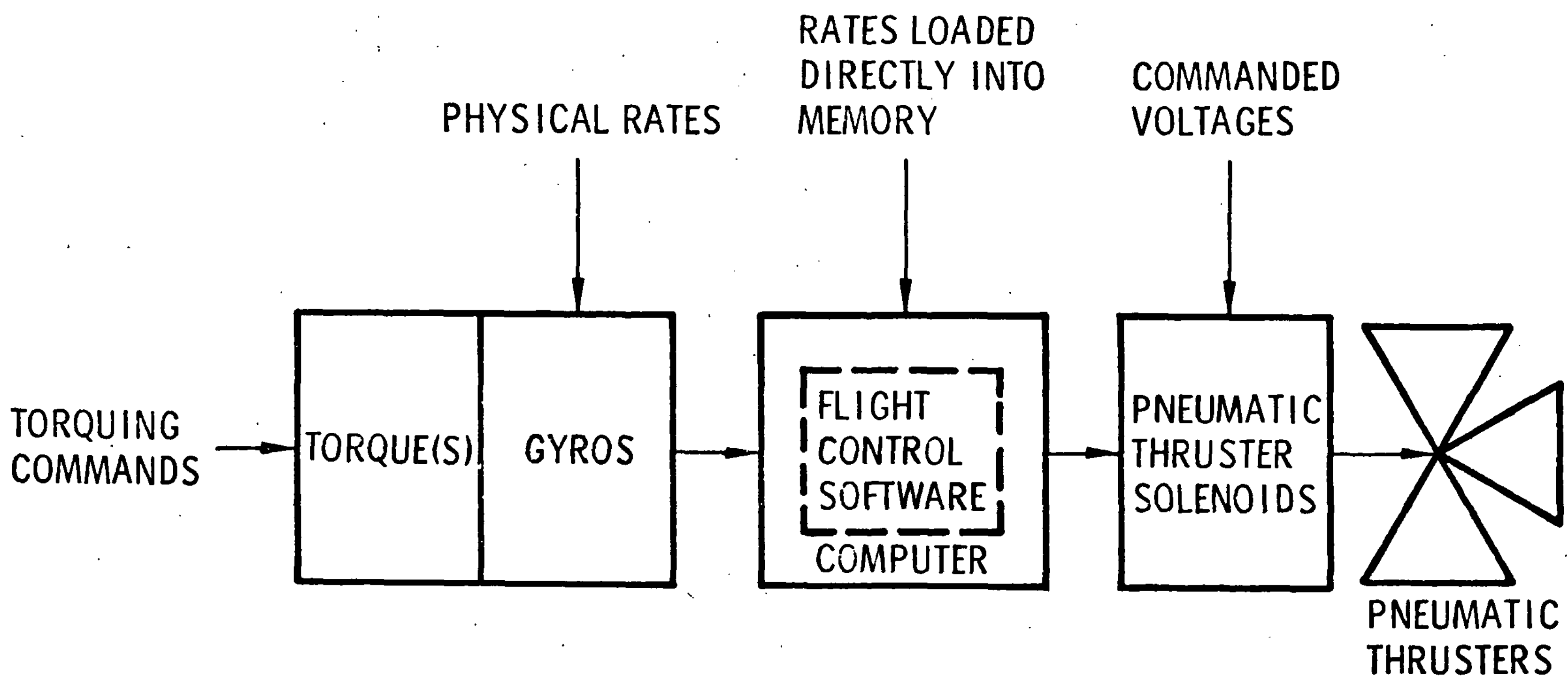


Fig. 3-28 Example of Various Levels of Tests Available on ITP

Fuel tank temperature
Oxidizer tank temperature
Helium tank pressure
Helium tank temperature
N_2 tank pressure
N_2 tank temperature
Fuel/oxidizer leak detectors
Oxidizer pump inlet temperature
Oxidizer pump inlet pressure
Hydraulic oil pressure
IAS input voltage and current
Computer voltage and current
Main bus voltage and current
Gyro bus voltage and current
Gyro temperatures
Accelerometer data output (prelaunch and deployment)
Fuel pump inlet pressure

3.4.2.3 Alignment. The Agena guidance system will be aligned independently from the shuttle guidance system; procedures similar to those currently employed with expendable booster flights will be used. No modifications are required in the Agena guidance system, although GSE for precise azimuth alignment may be required for missions that require accuracy better than that available by gyrocompassing.

3.4.2.4 Guidance System Update. The Agena guidance system can be updated before deployment from the orbiter and during the Agena flight phase by transferring guidance constants and commands from the orbiter computer.

The following requirements would be imposed on data transferred from the shuttle computer to the AGS computer:

- Format: 20 bit words, transferred sequentially; logical 1 = $+5V^{+0.5V}_{-2.5V}$; logical zero = $< 2.5V$
- Maximum bit rate: Up to 1 million bits/sec
- Minimum bit rate: N/A
- Minimum spacing between words: 0.15 msec (could be reduced to 0.02 msec by AGS software modification if necessary)
- Maximum spacing between words: N/A

3.4.3 Orbit Accuracies

Predicted one-sigma dispersions in orbit parameters are presented in Table 3-9 for the three design missions, based upon the use of the AGS. For the multi-orbit mission, only the errors into the 600 nm circular orbit were generated for this study. However, since there will be command capability to provide updated ephemeris data to the guidance computer, it is expected that the results shown for the 600 nm circular orbit will be applicable to the other low earth orbits specified. For purpose of the analysis it is assumed that the AGS navigates from the ground up, that no optical azimuth corrections are available, and that no attitude, position, or velocity updates are received from the orbiter prior to separation.

Table 3-9
AGS AGENA 1-SIGMA INJECTION ERRORS

Mission:	Synchronous Equatorial	600 nm Circular Sun Synchronous	Planetary (Mars – Viking)
Inclination (deg)	0.0492	0.0681	0.00527
Eccentricity	0.772×10^{-3}	0.200×10^{-3}	0.287×10^{-3}
Period (minutes)	-2.08	-0.10	–
Apogee Altitude (nm)	33.31	2.38	–
Perigee Altitude (nm)	-38.83	-2.38	–
Velocity (ft/sec)	–	–	3.15
Flight Path Angle (deg)	–	–	0.620×10^{-3}
Azimuth (deg)	–	–	0.0421

3.5 ELECTRICAL POWER SUBSYSTEM

The Agena tug electrical power system requirements and resulting design are direct functions of the mission power profile. Direct current power to support prelaunch and captive flight requirements are provided by the orbiter through the Agena/payload service panel located in the orbiter cargo bay. Just before deployment the Agena and payload are switched to internal power by command from the Agena tug specialist station located in the orbiter crew compartment. At this command the Agena tug provides electrical power to all Agena subsystems.

The electrical power requirements of the payloads have not been defined and therefore are not included in the following discussion. It may be assumed that the payloads are self supported with respect to electrical power.

3.5.1 Power Requirements

Prior to deployment electrical power will be supplied to the Agena and its payload by the orbiter. Orbiter power is 30 to 40 VDC, with a minimum allowance of 50 kw-hr. The 30 to 40 VDC will be stabilized and regulated at 28 VDC by a DC-DC converter and regulator located in the Agena/payload service panel for use by the Agena tug and the payload.

Mission power profiles for the three reference missions are presented in Figs. 3-29, -30, and -31.

These power profiles are based on a power consumption of 280 watts for the AGS and 60 watts for the communication system, except for the synchronous equatorial mission which requires 135 watts because of the longer transmitting distance. During engine burn periods an additional 103 watts are required to operate the propulsion system.

The interplanetary mission power profile (Fig. 3-29) will require only 340 watts average power for a time period of 30 minutes followed by an increase to 443 watts for 4.2 minutes during the Agena main engine burn. Total power required is 170 + 31 = 201 watt-hours for minimum battery energy capacity.

The synchronous equatorial mission power profile (Fig. 3-30) shows that, after deployment of the Agena from the orbiter, the Agena is dependent on battery power for approximately 15.4 hours. Average power requirement during this period is 415 watts. There are also three Agena engine burn periods that result in an increase of 103 watts from the battery supply. Each of these engine functions produces a peak power demand of 518 watts to be supplied by the battery. Total power required for this mission is 6400 watt-hours.

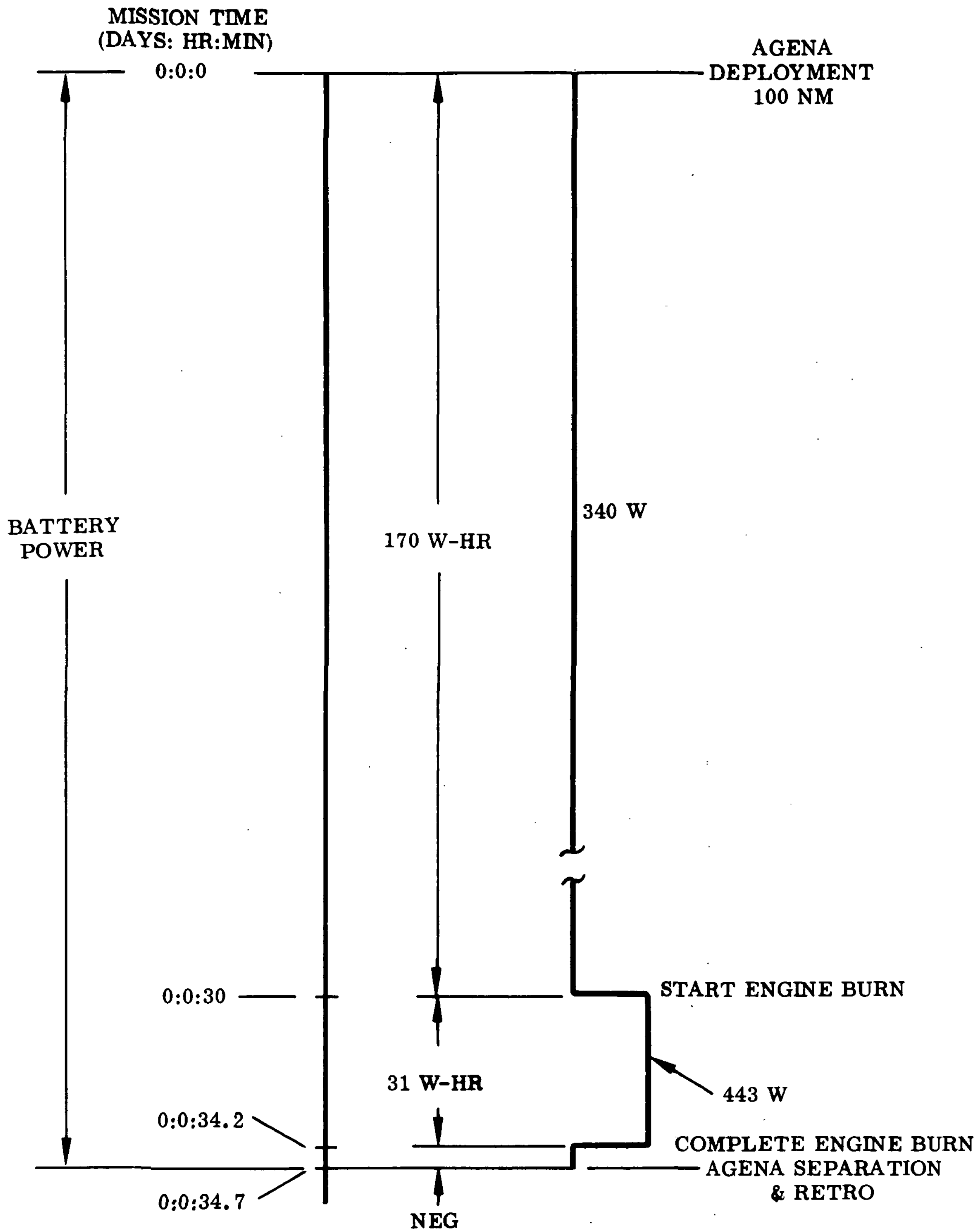


Fig. 3-29 Mars-Viking Interplanetary Mission Power Profile

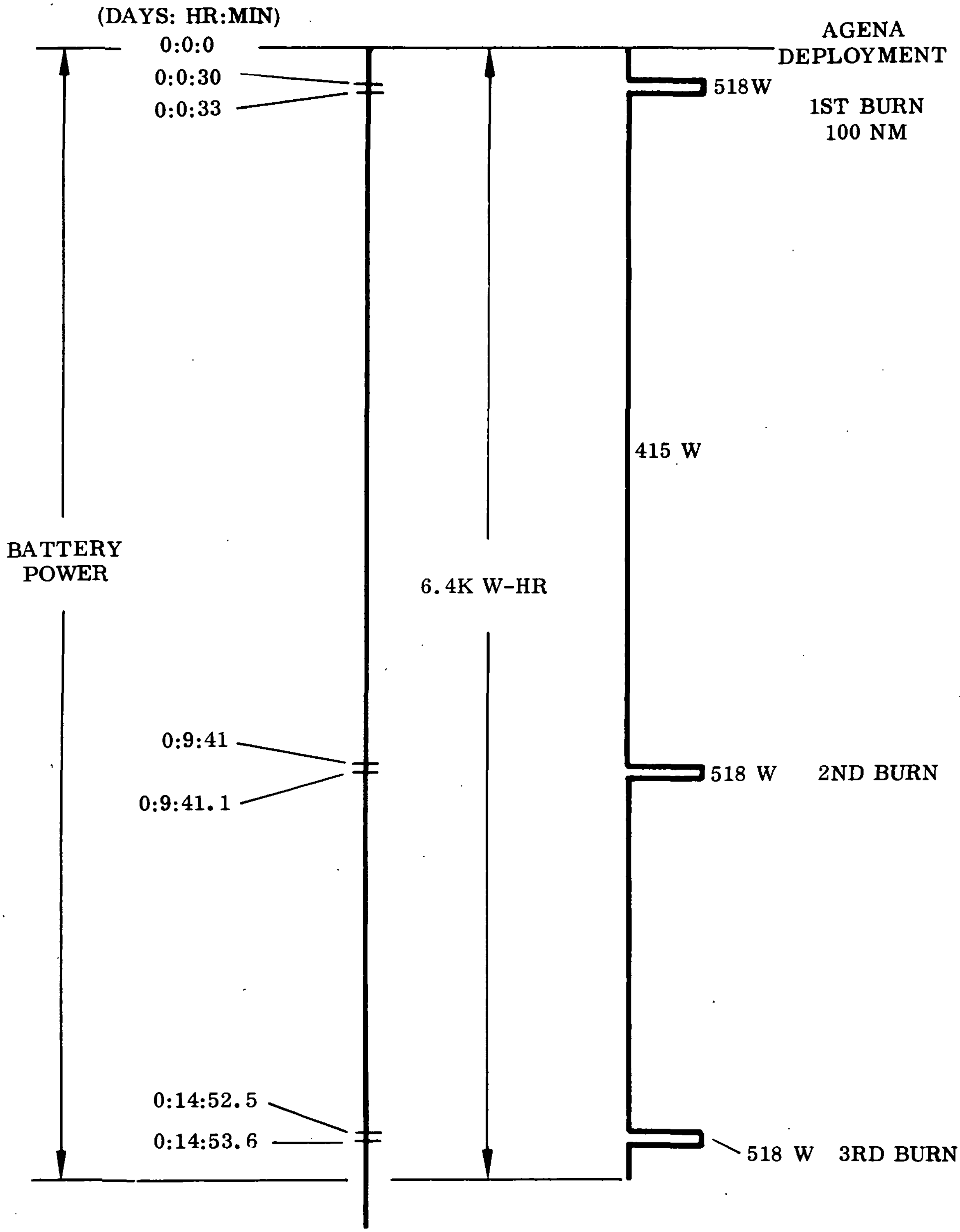


Fig. 3-30 Synchronous-Equatorial Mission Power Profile

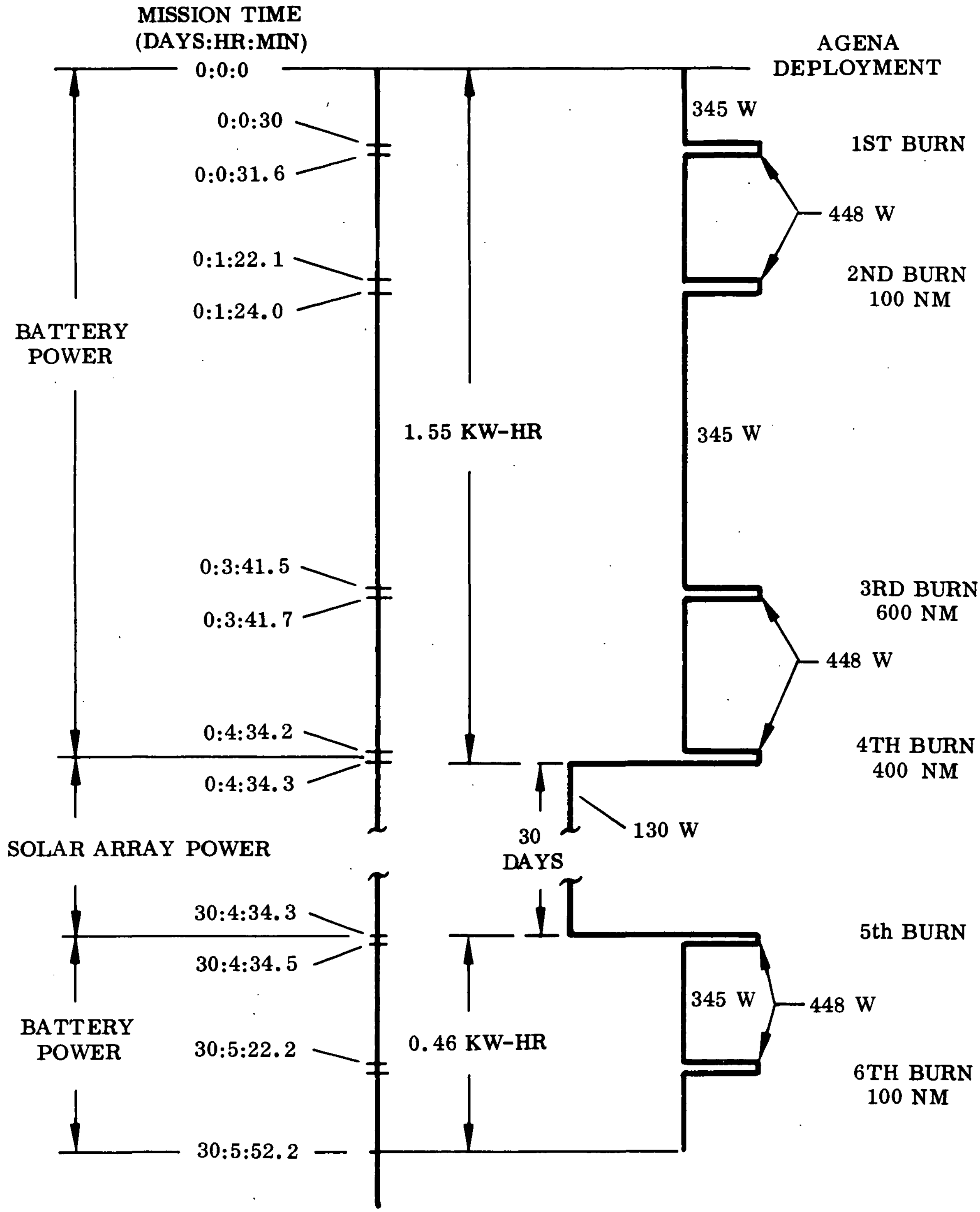


Fig. 3-31 Sun-Synchronous Mission Power Profile

The sun synchronous mission (Fig. 3-31) will require approximately 1550 watt-hours of power between shuttle deployment and insertion into 400 nm circular orbit. The average power requirement of 130 watts during the 30-day orbit stay period reflects the reduced guidance demands of the AGS/DACS system operation. The final mission phase – return to the 100 nm circular orbit – will require approximately 460 watt-hours.

The power requirements for the synchronous equatorial orbit mission and the planetary probe mission can best be satisfied by means of primary batteries. For the planetary mission the standard ascent Agena silver-zinc battery weighing 32.2 pounds can be used. The higher demands of the synchronous equatorial mission will require a larger capacity battery weighing approximately 120 pounds. This battery is compatible with the volume and structural constraints of the Agena and will not require modifications for incorporation.

The longer, 30-day, mission would impose severe weight and volume penalties if primary batteries are used. Therefore, it is proposed that a solar array system be employed to provide power during the orbit stay and to recharge the battery pack for use during the return to low orbit. A 52-pound rechargeable battery would be required for this operation plus the necessary solar panels, charge controller, and circuitry.

3.5.2 Circuit Design

A schematic diagram of the Agena space tug electrical power system for the two missions using primary batteries is presented in Fig. 3-32. The sun synchronous mission, which will use solar panels, is shown in Fig. 3-33. The systems are basically the same, except for the solar panels and charge controller.

The DC/DC converter accepts a 30 to 40 VDC input from the orbiter power source and conditions and regulates this voltage to a +28 VDC, ±1 percent output to the Agena power distribution box and charge controller.

The power distribution box serves to accept and switch regulated +28 VDC power to the using equipment. The distribution system provides the necessary fusing, switching, and telemetry monitoring points to control the power requirements.

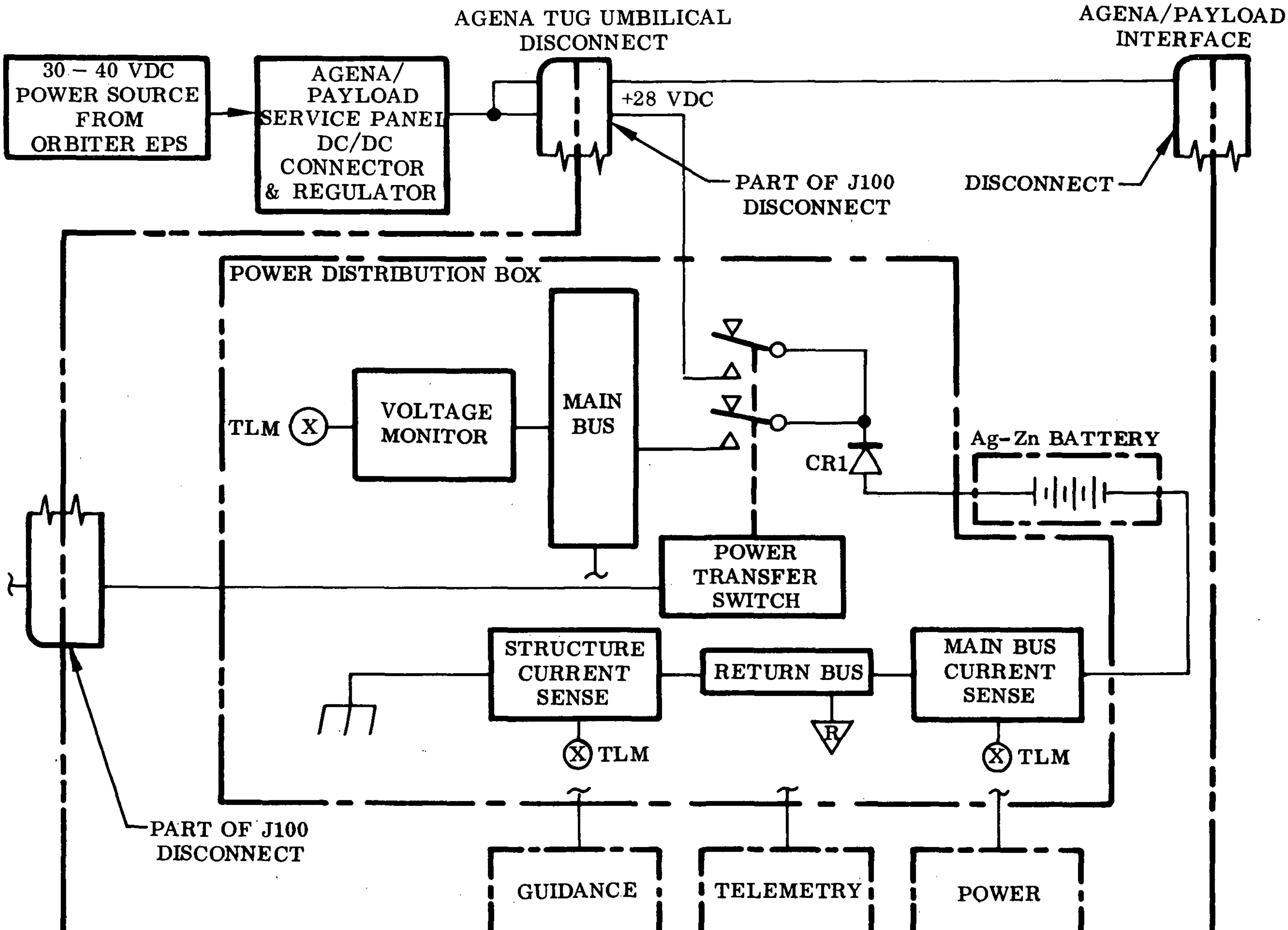


Fig. 3-32 Agena Tug Electrical Power System – Mars-Viking & Synchronous-Equatorial Mission Configuration

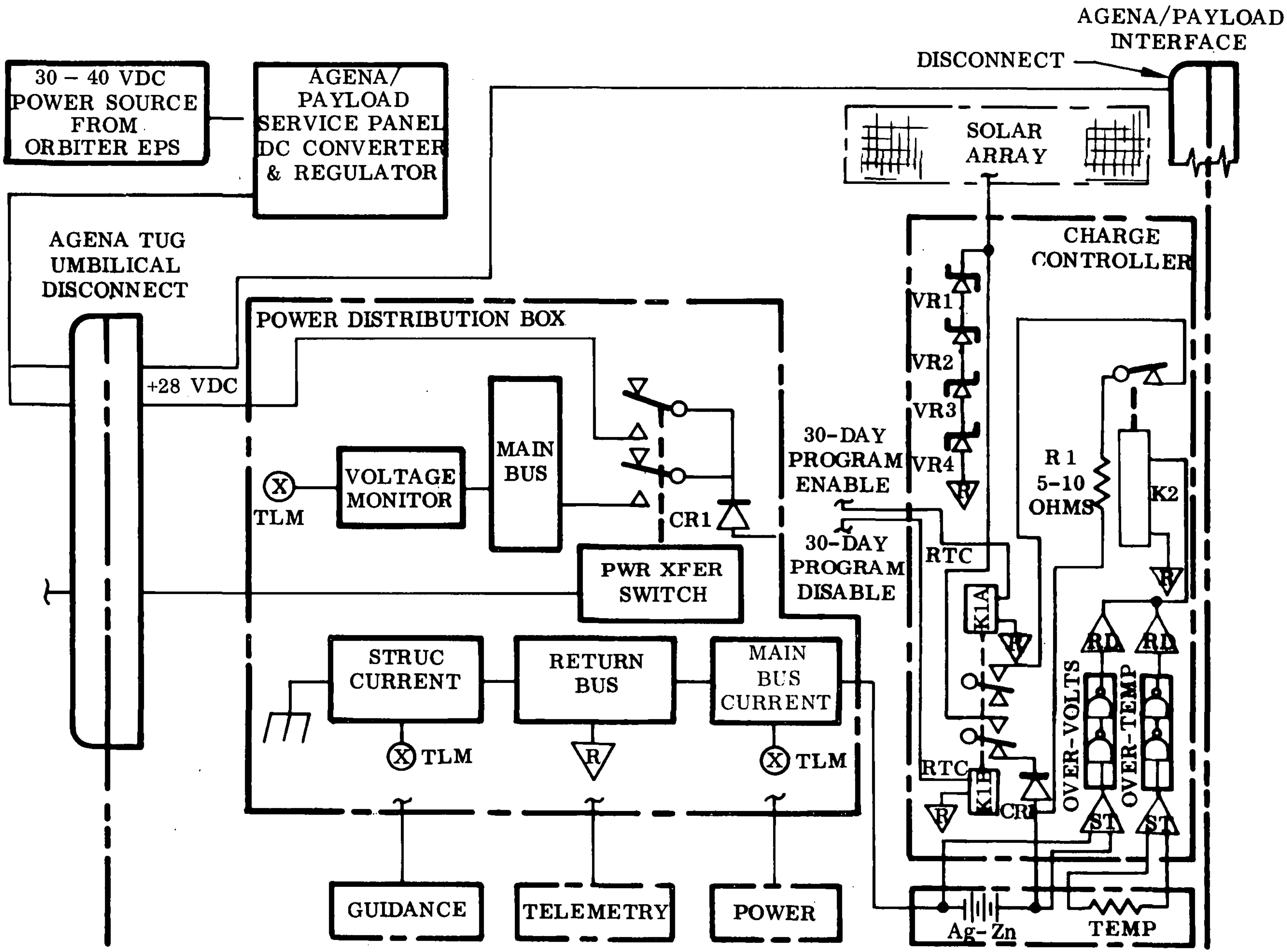


Fig. 3-33 Agena Tug Electrical Power System – Low-Earth-Orbit Sun-Synchronous Mission Configuration

The charge controller functions mainly as a switching device, which accepts inputs from a solar array and silver-zinc battery and enables either of these power sources to supply vehicle power when power from the orbiter is removed. The charge controller is controlled by realtime command.

Power is also supplied directly to the payload by the DC/DC converter through the J-100 umbilical. Distribution of this power supply is a payload responsibility.

The power transfer switch is closed by command from the Agena specialist station, enabling the Agena load system to receive power directly from the DC/DC converter. Once closed, the transfer switch contacts remain closed throughout the mission. Power can be removed from the Agena by command (prior to deployment) if required for vehicle safing in case of mission abort. After deployment no control of the transfer switch is necessary or desirable.

Load current and vehicle structure current (return) are sensed at the return bus and the current values conditioned for compatibility with the telemetry system. Concurrently the 28 VDC main bus voltage is sensed and provided to the telemetry system. If required, these sensed values can be paralleled and provided to the orbiter Agena specialist display console through the Agena J-100 umbilical.

The charge controller nominally accepts input from either the solar array or battery. At the moment of Agena/spacecraft disconnect from the orbiter, the battery assumes the load requirement of the 28 VDC bus through contacts of K1 latching relay. A power isolation diode, CR1, prevents the possibility of further charging of the battery while the battery continues to serve as the 28 VDC source of power during the initial stages of flight.

At the desired time in the flight program, a real-time command, 30-Day Program Enable, derived from the vehicle command system energizes relay K1 to transfer the load to the solar array. The solar array, having assumed the load, continues to provide DC power to the load bus and simultaneously begins a slow recharge of the battery through current limiting resistor, R1. Zener diodes VR1 through VR4 regulate the output voltage from the solar array if the array itself tends to have a greater than 30-volt level.

At the conclusion of the 30-day program, another command, 30-Day Program Disable, switches relay K1 to again permit the battery to supply the vehicle load. The battery continues to supply DC power to the Agena subsystems for the remainder of the flight.

The batteries used for the Agena space tug have sufficient wet stand life to permit a 2-week ground hold prior to launch without degrading the electrical power system performance or reliability.

3.5.3 Equipment Requirements and Availability

A preliminary list of the required Agena electrical power system equipment and its availability is presented in Table 3-10. Two equipment status symbols are used for cabling, indicating that some of the required cables can be used as is and others will require modification.

A DC/DC converter having an input voltage handling capability of 30 to 40 VDC and regulated ±1 percent, ±28 VDC output of 600 watts* will have to be provided. Few power supply vendors have flight-qualified hardware featuring this high a power output. Those that do provide units of this power level are usually devoted to nonflight applications. One or two suppliers have indicated that a flight item could be produced from existing design, but consideration of modification and qualification to flight requirements must be pursued further.

Power distribution boxes have been developed for a number of LMSC programs. Most promising of these, for purposes of adaptability to the Agena space tug is the Agena baseline configuration distribution box. This box and the existing functions can be used with only minor modification. Essentially all that is involved is some rewiring of the power transfer switch.

The battery charge controller, required for the sun synchronous mission only, is a new item requiring development and qualification to produce a flight qualified item.

*No allowance has been made for payload peculiar power requirements; these needs must be known before the DC/DC converter can be sized.

Table 3-10

EQUIPMENT REQUIREMENTS AND AVAILABILITY

HARDWARE DESCRIPTION	LMSC PART NO.	MANUFACTURER	MISSION-PECULIAR REQUIREMENT AND STATUS: SYNC EQUATORIAL	SUN-SYNC	MARS-VIKING
1. DC/DC Converter and Regulator	–	TBD	C	C	C
2. Charge Controller	–	LMSC	Not Needed	D	Not Needed
Relay	–	Leach			
Relay	LS 41004				
Diode	LS 41064				
Zener	LS 41285				
Resistor	–	Dale			
Schmidt Trigger	LS 41092				
Buffer Amp	LS 41077				
Relay Driver	–	Motorola Jan ZN 3444			
3. Power Dist Box	1389613	LMSC	A	A	A
Power SW S-1	1062515				
Current Sensor	LS 41161-31				
Current Sensor	LS 41161-34				
Voltage Mon	1389627				
Pyro Diode	1390020				
J1-J5 + J500	LS 41035				
4. Solar Array	–	LMSC	Not Needed	D	Not Needed
5. Battery	(Various)	Various	Type IH A	Type VIA B	Type IVB A
6. Cabling	–	LMSC	A and B	A and B	A and B

A – Existing hardware used as-is
B – Revised for mission-peculiar requirement
C – New hardware for shuttle compatibility
D – New hardware for mission-peculiar requirement

Photovoltaic energy devices for spacecraft power sources will probably continue to be the prime candidate for most long-duration missions throughout the 1970 to 1980 period. Solar arrays have therefore been selected for use in the power supply system for the long-duration (30-day) low earth orbit mission. LMSC-designed solar arrays will deliver electrical energy densities of approximately 30 watts per pound of solar array system. At present technology levels solar arrays are the lightest and least expensive power source available for power levels of 100 watts to more than 20,000 watts. The sun synchronous mission requires on-orbit power in the 100-to-500 watt range.

Solar arrays, sun oriented to maximize output power, convert incident solar energy into electrical energy at efficiencies of 8 percent to 12 percent.

For the sun synchronous orbit the orbit plane to sun relationship is not changing as a function of orbit precession, thus simplifying the orientation of the solar arrays and eliminating the necessity for sun tracking.

Two Agena solar array installation arrangements lend themselves to this mission. The simplest requires that a given surface area of the vehicle skin be covered with solar array modules. Any available flat or curved surface such as the propellant tanks could be used. Curved surfaces, however, provide power as a direct function of the projected surface area normal to the solar incident energy. Curved surfaces thus are inefficient by a factor of $\frac{\pi}{2}$ requiring approximately 50 percent more module area for a given energy output.

An alternative choice would be to stow panels in a convenient place (probably on the Agena aft equipment rack) and deploy the array after injection into the 400 nm orbit. This method has been used by LMSC on several Agena and other spacecraft programs. Figure 3-34 presents a typical Agena solar array installation in the deployed position. For the Agena tug application only four panels of the illustrated type would be required. Present Lockheed design, including all solar panel losses, typically have an array power density of about 9.5 watt/sq ft. The above recommended array size is based on existing flight hardware, provides 47.0 watts of power per panel at $77^{\circ}F$.

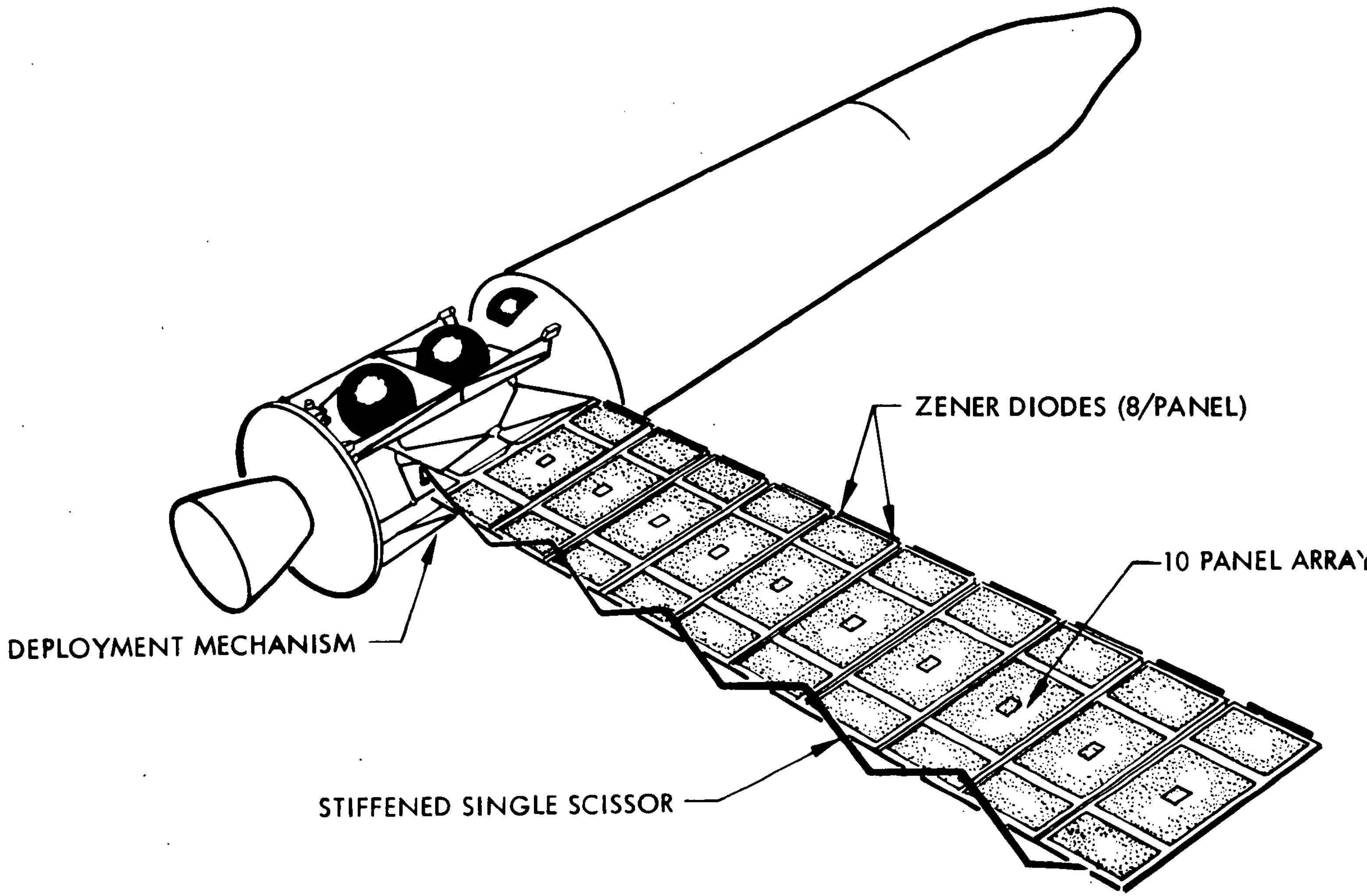


Fig. 3-34 Typical Operational Agena Solar Array Installation

The Lockheed-designed Flexarray, presently being developed, provides a 70-watt modular building block panel. The honeycomb panel and flexarray substrate are illustrated in Fig. 3-35.

Before the main engine burn for return to low orbit is initiated, extendible panels would either be retracted or jettisoned.

3.5.4 Main Electrical Umbilical

All of the electrical connections to the Agena, both with respect to electrical power and data management will go through the main electrical disconnect, J-100.

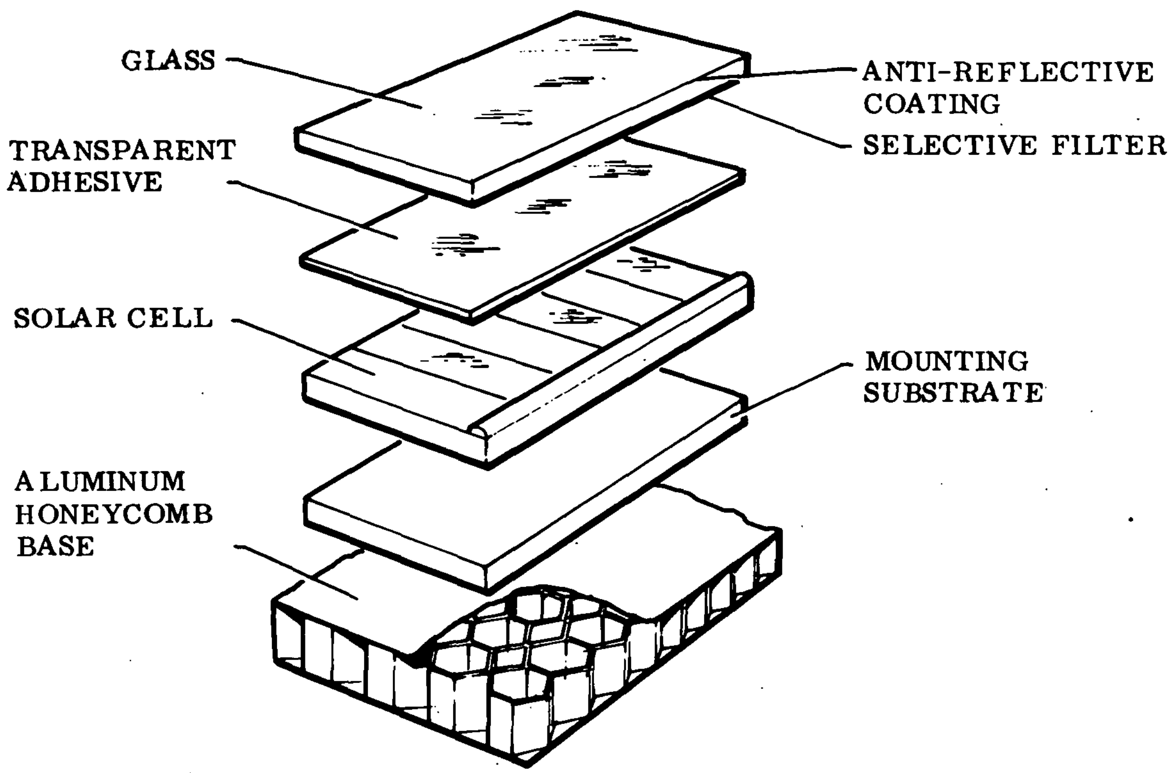
The umbilical retract mechanism for the main electrical umbilical (MEU) will be similar to that used for the propellant fill couplings and will employ the same drive mechanism and structural elements. Existing electrical umbilical will be modified to adapt the electrical interface to the space tug/payload application. Figure 3-36 shows the design features of the retract system for disconnecting the orbiter power system from the space tug vehicle. Modifications to the MEU will consist of removing the present center mechanism and replacing the connect/disconnect with an external latching mechanism. The new latching mechanism will contain a manual override which will allow a manual disconnect. The manual disconnect will in one motion disconnect the MEU, disengage the drive mechanism, and retract the MEU at least 12 inches.

3.6 COMMUNICATION SUBSYSTEM

The Agena communication system must be designed to be compatible with the shuttle system and its communication equipment.

A few of the most significant design requirements with respect to the communication system (telemetry, tracking, and command) are enumerated below:

a. For normal conditions following deployment by the shuttle, any required monitoring of telemetry data or command and control of the Agena vehicle will be performed by available ground stations. As a design goal, the shuttle orbiter should have the option of controlling and monitoring the Agena.



RIGID SOLAR PANEL CONSTRUCTION

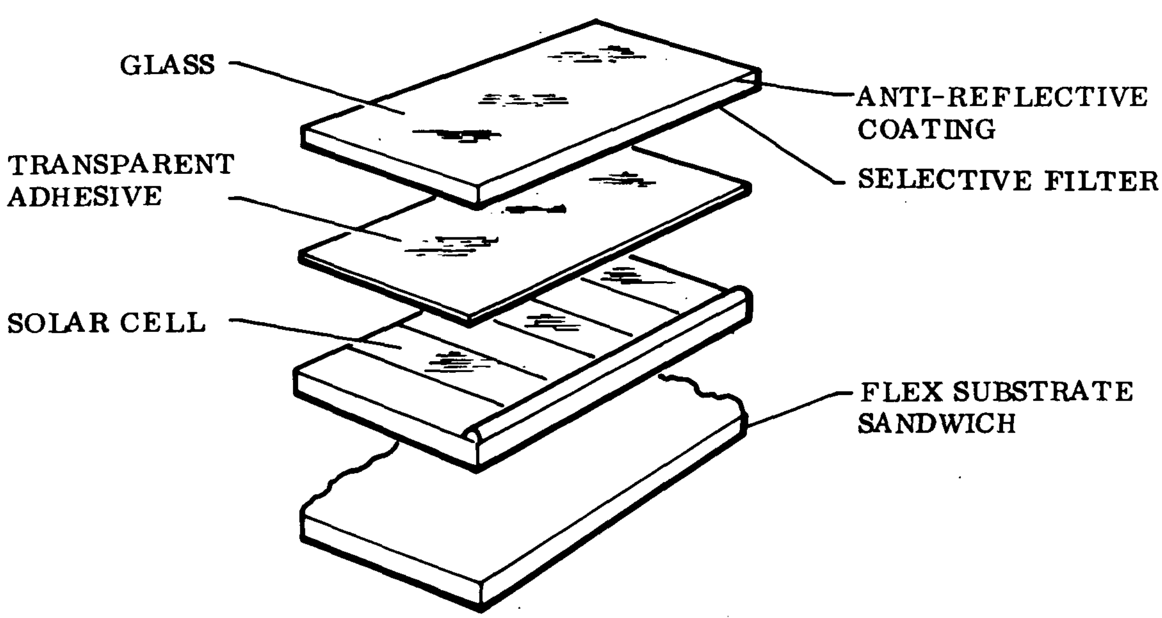


Fig. 3-35 Solar Panel Construction

b. The Agena communications system must be capable of supporting the following typical missions:

Mission I – Synchronous Equatorial Orbit
Mission II – Interplanetary Injection
Mission III – Sun Synchronous Orbit with Return

c. Provide a command system for updating the Agena guidance system subsequent to deployment of the Agena from the shuttle.

d. The Agena communications system must be compatible with the shuttle communications and data display system, both prior to and subsequent to deployment. (Refer to Item a.)

e. The Agena communications system must be compatible with unified S-band ground support equipment.

Although the baseline Agena communication subsystem is not unified S-band compatible, the requirement can be satisfied with equipment that is qualified by test and will require only minor modifications.

Prior to deployment 25 kbps and 63 kbps digital data will be hardlined from the Agena to the orbiter. The Agena system design is based on the assumption that after deployment the orbiter will be able to receive 63 kbps digital data, provide realtime readout of mission critical parameters, and relay all the data to the ground support stations at 25 kbps by reprocessing the received 63 kbps data. If the above is not possible, the Agena PCM telemeter can be modified to provide two output rates: 63 kbps and 25 kbps. The 63 kbps rate would be used for direct communication with ground stations and the 25 kbps rate for communications with the shuttle.

3.6.1 Configuration

The flight configuration and RF spectrum of the Agena communications (telemetry, tracking, and command) system are shown in Figs. 3-37 and 3-38. The vehicle data are encoded by the pulse code modulation (PCM) telemeter, which biphase modulates the baseband 1.024 megahertz (MHz) subcarrier oscillator (SCO). The output of the baseband is fed to the transmitter and then coupled to the ascent antenna.

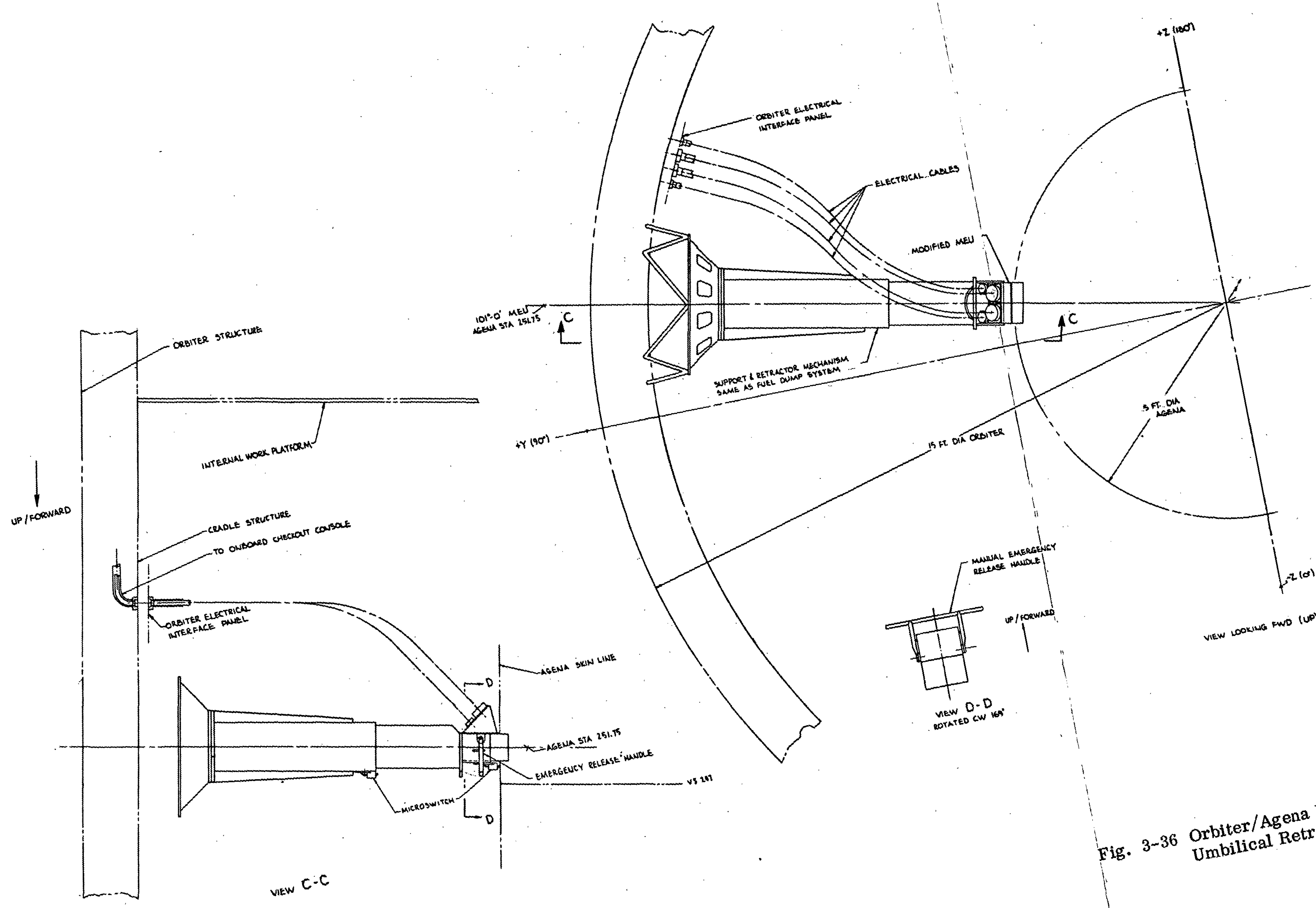


Fig. 3-36 Orbiter/Agena Main Electrical Umbilical Retract System

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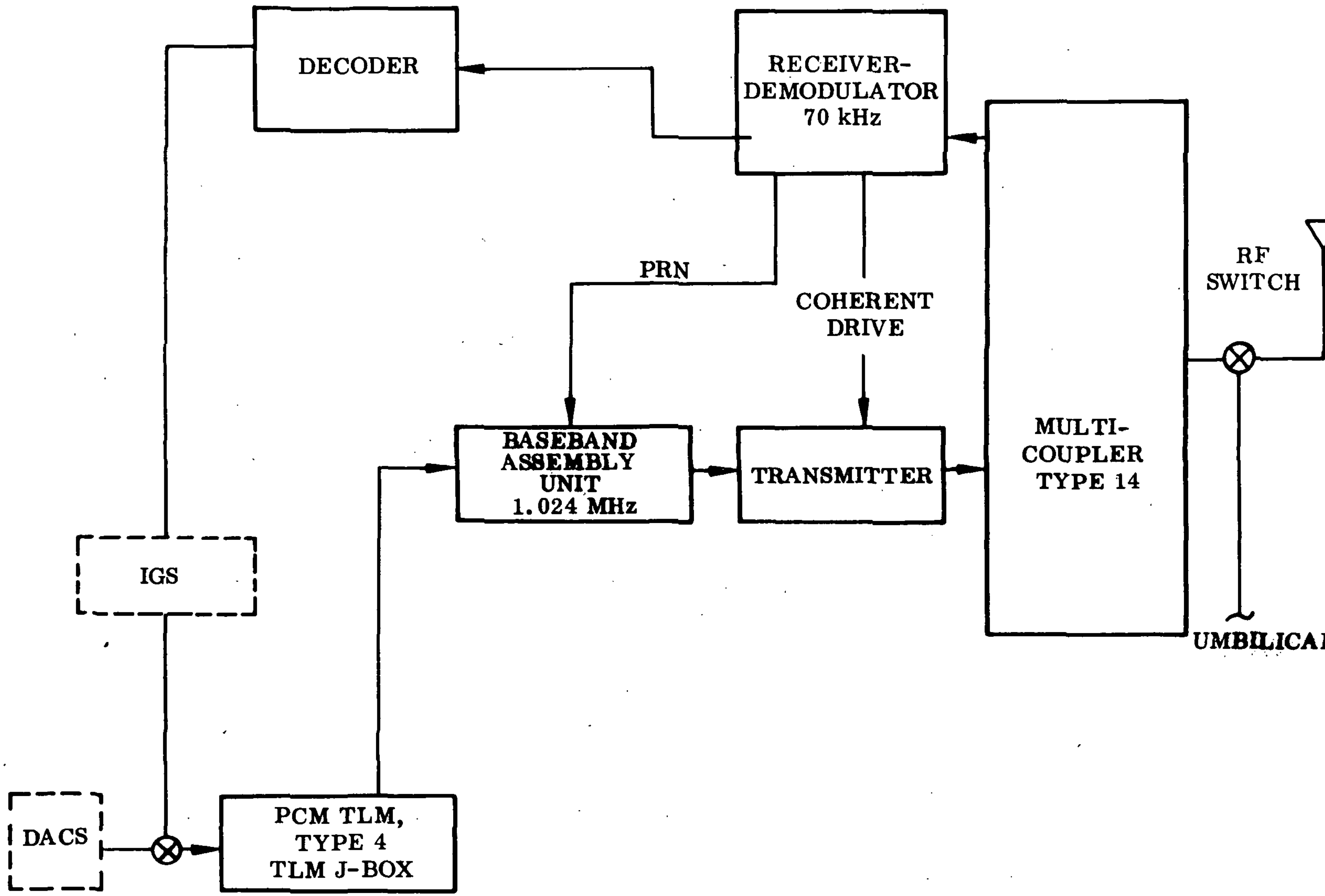


Fig. 3-37 Communications System

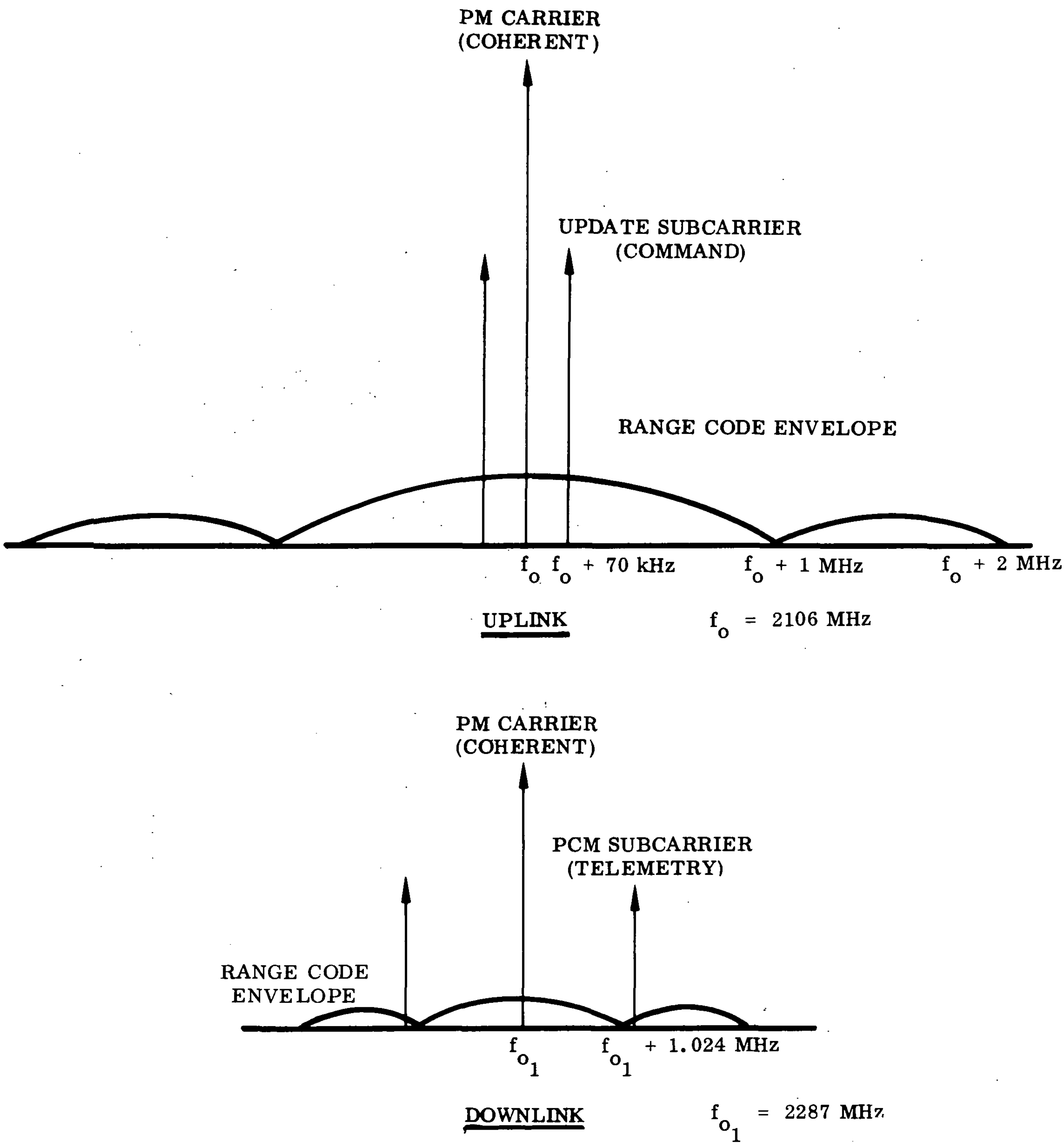


Fig. 3-38 RF Spectrum

Digital commands are received on the uplink through the antenna and multicoupler. The receiver/demodulator output is processed by the decoder which has the capability of supplying 64 realtime commands and updating the guidance computer.

Tracking is accomplished through range, range-rate, and angle-of-arrival information. The pseudo-random noise code (PRN) sent to the vehicle, then received again on the ground, provides range data. The coherent uplink/downlink carrier doppler shift provides range-rate data. Angular position is determined from the apparent angle-of-arrival of the modulated signals transmitted by the vehicle.

The Agena communications system is capable of transmitting the required RF information to permit a rendezvous between the shuttle and the Agena. The information can be transmitted to a ground station for computer processing and then relayed up to the shuttle, or the shuttle can receive the RF data directly from the Agena. The Agena transmits range and range-rate information; therefore, only one other parameter is necessary for a rendezvous mission, angle-of-arrival of the Agena RF carrier. These data are obtained as follows: a feed arrangement and comparator network combine the signals from four feed horns to form a sum, or reference signal, and two orthogonal error signals. When the shuttle or ground antenna is properly pointed at the Agena, the output of the sum channel is at a maximum, and the outputs of the error channels are zero. Antenna misalignment produces error channel signals. The phase of these signals, relative to the reference channel, indicates the direction of displacement; their amplitude, for small displacements, is directly proportional to the angular misalignment.

The shuttle/Agena communication interface is shown in Fig. 3-39. All cargo-bay, deployment, and Agena/spacecraft monitors hardlined to the Agena/Payload service panel will be processed by the standard interface unit (SIU) and relayed to the shuttle data bus at a rate of 25 kilobits per second (kbps). The Agena telemetry output of 62.5 kbps is sent directly to the shuttle T/M encoder and then to the ground on the high rate downlink. The Agena can be commanded via the data bus.

The individual components making up the communication system are described in the following paragraphs.

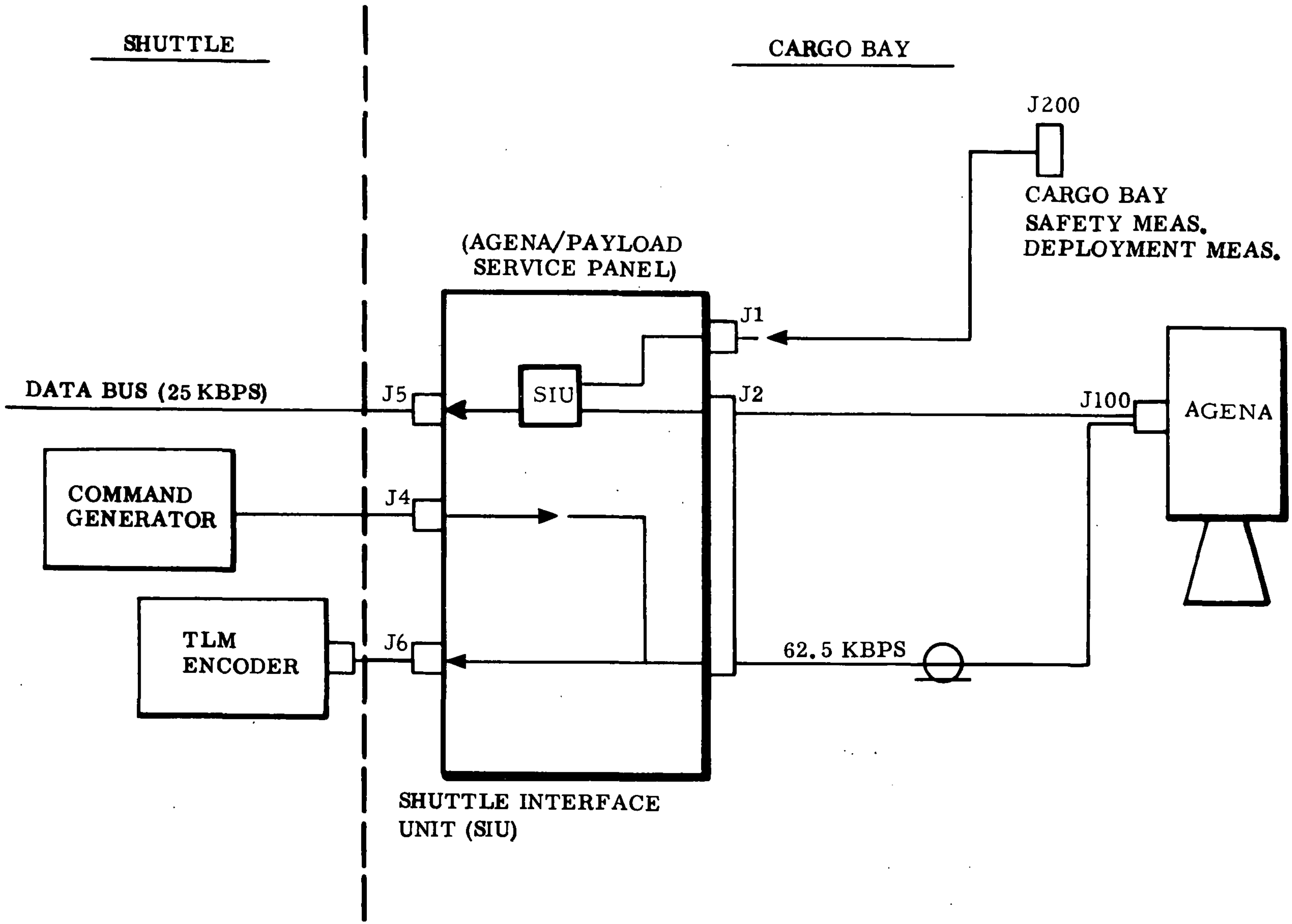


Fig. 3-39 Shuttle/Agena Tug Interface

The Agena status data are time-division multiplexed and encoded by the PCM telemeter Type IV and transmitted from the Agena via the baseband assembly unit, transmitter, and antenna. Both the telemeter and J-box at the input to the telemeter have been qualified by test and have a successful flight record. The J-box provides a means to implement signal conditioning circuits for monitors having a voltage level greater than 5 volts. Also, monitors that must be supercommutated are jumpered within the box.

The PCM telemeter encodes data into a non-return-to-zero level (NRZ-L) at a rate of 62.5 kbps. The main frame consists of 32 eight-bit words, which means the sampling rate is

$$\frac{62.5 \text{ kbits}}{\text{sec}} \times \frac{1 \text{ word}}{8 \text{ bits}} \times \frac{1 \text{ main frame}}{32 \text{ words}} = \frac{244 \text{ main frames}}{\text{sec}}$$

The main frame usage is as follows:

Function	Number of MF Words
Frame Sync	3
Subframe ID	1
Guidance Digital Data	12
Subframes	5
Analog Inputs	11

There are two internal submultiplexers: one with 64 words and a sampling rate of 3.8 samples per second and the other with 64 words but a sampling rate of 15.3 samples per second. The latter submultiplexer has an input capability of 56 analog signals and 64 bilevel signals.

All data gates are MOSFETS, which provide high input impedance and data isolation because of low leakage current. Because of the eight-bit encoding, the telemeter can resolve any voltage level to within 20 millivolts. The total error of the telemeter is less than ±1 percent.

It is understood that the unified S-band ground stations have narrowband bit synchronizers with fixed bit rates. Since all bit synchronizers can lock on to any bit rate that is within 10 percent of nominal, the Agena bit rate of 62.5 kbps is within the capability of the bit synchronizer at a nominal rate of 65.54 kbps. If the Agena bit rate is unacceptable, the telemeter can be modified to have a bit rate of 51.2 kbps, which is a nominal USB rate.

3.6.1.1 Baseband Assembly Unit. The baseband assembly unit performs two functions in the Agena communications link:

a. Accepts PRN ranging signals for turnaround to the downlink
b. Accepts PCM telemetry bit stream which in turn modulates a transmitter

The uplink PRN ranging code is one of the most important signals generated by the ground station or shuttle. The code is used to determine the radial range between the ground station or shuttle and the Agena. A continuous running binary waveform at a nominal rate of one million bps is transmitted to the Agena on the uplink. This PRN signal is then sent through an 800 kHz low-pass filter in the baseband unit, where it is summed with the 1.024 MHz subcarrier before phase modulating the transmitter carrier.

The PCM telemetry bit stream biphase modulates the 1.024 MHz subcarrier in the baseband unit, is bandpassed filtered and summed with the PRN ranging code. Before going to the biphase modulator, the PCM bit stream is inverted, shaped, and amplified into a suitable modulating signal and its complement. The biphase modulator is basically an exclusive OR gate that passes one phase of the subcarrier for data ones and the phase complement of the other subcarrier for data zeros. The output of the modulator is made up of the subcarrier or its complement, varying in accordance with the ones and zeros contained in the input data signal.

The baseband assembly unit is fully redundant and qualified by test. Provision is made in the baseband unit for addition of a voice channel to be frequency modulated on a 1.25 MHz subcarrier.

Five external monitoring signals are provided by the baseband unit to allow remote indication of its operational status. These outputs consist of the following:

a. Power converter output voltage
b. ON-OFF monitors
c. Temperature monitor

3.6.1.2 Transmitter (2 Watts). The unified S-band compatible phase modulated transmitter receives a composite signal, consisting of the PRN ranging code and the 1.024 MHz subcarrier from the baseband unit. This signal is applied to the auxiliary oscillator-phase modulator, where it is phase modulated on a 70 MHz carrier. The carrier frequency is supplied by (1) the local oscillator or (2) an accompanying receiver, when it has phase-locked on an incoming signal, thus providing coherent transponder operation of the transmitter-receiver combination. The modulated carrier is amplified, filtered, and frequency multiplied by a series of three modules: the X4 exciter-multiplier, the power amplifier, and the X4 varactor multiplier. The power converter provides two regulated voltage outputs for operation of the transmitter circuitry and, in addition, furnishes a triggered square wave to accomplish mode switching of the auxiliary oscillator phase modulator. For a specific S-band carrier frequency in the noncoherent mode, the 70 MHz crystal is changed. The transmitter provides five diagnostic monitoring signals to allow remote indication of its operational status.

a. Temperature Monitor
b. ON-OFF Monitor
c. Power Converter Output Voltage
d. Internal Pressure
e. Operational Mode Monitor

3.6.1.3 Transmitter/Power Amplifier. For missions with maximum altitudes of 1000 miles or less, the 2-watt transmitter is sufficient to assure adequate link margin. The synchronous equatorial orbit mission, altitude 19,000 nm, will require more output power from the Agena transmitter (8 to 10 watts total). The simplest solution, from a standpoint of input power, weight, volume, and cost, is to provide a power amplifier at the output of the existing two watt transmitter. Although the conic power amplifier is a wideband amplifier, it can be easily modified to reduce the bandwidth.

2.6.1.4 Antennas. An RF multicoupler is connected to the input of the Type 28 antenna so that one antenna can be used for both the receiver uplink and the transmitter downlink. The RF loss through the multicoupler is only 0.8 dB for the receiver and 0.4 dB for the transmitter.

The Type 28 antenna has a crossed-dipole feed with a 19-inch diameter semiflat reflector. Approximately +6 dB is achieved through the antenna due to the combination of a +3 dB gain and the antenna circular polarization.

A single-pole, two-throw coaxial switch is available at the output of the multicoupler for closed-loop operation of the communications system in the shuttle.

For a synchronous equatorial orbit, an increase in the communications RF link is needed. Addition of a 5-foot diameter parabolic antenna yields a gain of approximately 26 dB. Another RF switch will be added to switch from the ascent antenna to the orbit antenna at approximately 1000 nm.

3.6.1.5 Receiver-Demodulator. The receiver/demodulator performs three important functions in the operation of the Agena communications system:

a. Amplification of PRN Range Code
b. Coherent Drive to the Transmitter
c. Demodulation of the 70 kHz Command Subcarrier

The simplified block diagram of the receiver/demodulator (Fig. 3-40) shows the synthesis of the above functions.

The receiver/demodulator incorporates a coherent phase-lock receiver with a 221/8 received-to-transmitted drive ratio. The input signal is accepted by the RF converter, where it is mixed down to approximately 48 MHz, amplified, and fed to the IF amplifier/mixer module. Here it is mixed again, producing a constant-frequency output of 12.25 MHz. The narrowband phase detector compares the phase of the IF signal and a 12.25 MHz reference signal from the reference generator. The detected phase error is applied as a correction voltage to the VCO which operates at a nominal frequency of $2f_1$.

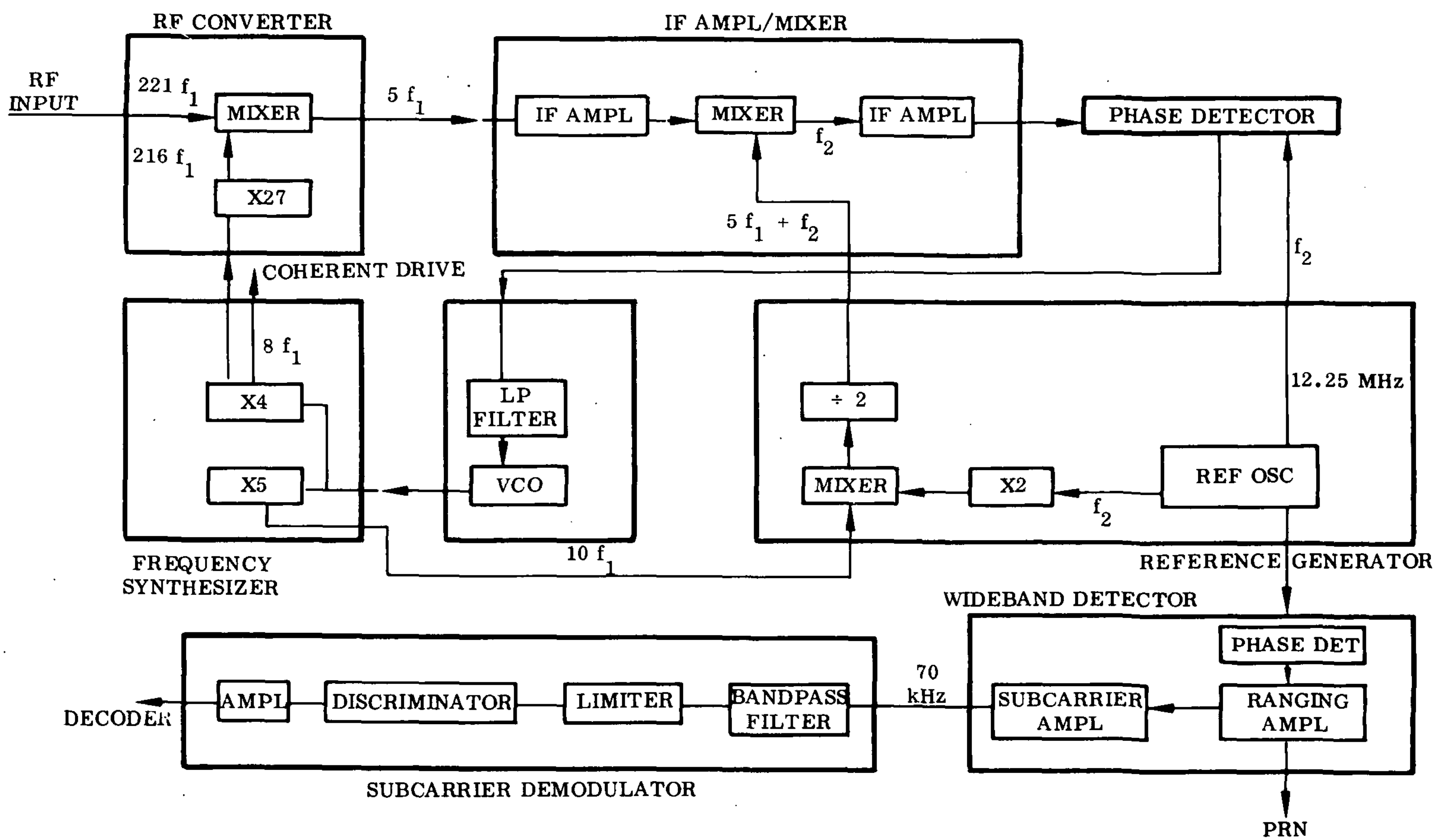


Fig. 3-40 Receiver/Demodulator

(It is this VCO frequency that is adjusted to be compatible with the USB uplink frequency). The corrected (phase-shifted) output of the VCO is multiplied in the frequency synthesizer. One output of frequency synthesizer provides the 216 f_1 frequency for the RF converter, which mixes with the 221 f_1 on the RF input to produce a 5 f_1 output. Another output of the frequency synthesizer goes to the reference generator, where the 10 f_1 signal is mixed and divided by two with the 2 f_2 to provide a 5 f_1 + f_2 to the IF amp/mixer module. The third output provides the 8 f_1 coherent drive to the transmitter.

The 70 kHz subcarrier is sent through a 70 kHz bandpass filter with a bandwidth of 20 kHz, limited, discriminated, amplified, and presented as an output to be further processed by the command decoder.

The particular method used by this receiver to synthesize the coherent ratio of 240/221 achieves two important objectives. First, through the use of double conversion technique, high-level subharmonics of the received frequency or first IF frequency are not generated, either as local oscillator signals or as mixer products. If products of this nature were generated, the receiver would tend to lock onto itself, seriously impairing its performance in the normal mode. Secondly, this particular design permits the selection of frequencies so that all circuitry and devices are operating conservatively.

Telemetry monitors provided in the receiver/demodulator are as follows:

a. Tracking Signal Output
b. Loop Stress
c. Command Signal Present
d. Temperature
e. ON-OFF
f. Power Converter Output Voltage

Modifications of the SGLS receiver/demodulator required to make it USB compatible are as follows:

a. Remove the Signal Conditioner Module
b. Remove the Times-Three Circuit in the Frequency Synthesizer
c. Remove the Times-Seven Circuit in the RF Converter and Replace it with a Times-27
d. Add a Subcarrier Demodulator Module.

3.6.1.6 Command Decoder. The digital command data are generated by bi-phase modulating a 2 kHz sine wave with one kbps PCM NRZ data. A 1 kHz sync tone is added to the above, and frequency modulated onto a 70 kHz subcarrier, which in turn phase modules the uplink carrier resulting in a pulse code modulated/phase shift keyed/frequency modulated/phase modulated (PCM/PSK/FM/PM) command data link.

The decoder receives the composite signal from the receiver containing the sub-bit information and synchronization and coherently demodulates the signal. It is then detected in a matched filter. A matched filter is used because it is an optimum detection method with an impulse response corresponding to the shape of the time signal to be detected.

This device integrates the signal applied to it for the duration of one bit interval. The output of the matched filter amplifier is fed to an inverter and to one trigger-set input of the decision flip-flop. The sub-bits are then decoded into info-bits (five sub-bits equal one info bit) by either a vehicle address info-bit detector or a remaining message info-bit detector. Two sets of detectors are required because the five-bit code for an info-bit "one and zero" changes after the vehicle address (info-bits 1, 2, and 3). After the vehicle address has been properly decoded, the message info-bit detector decodes the next six info-bits for real-time commands (64) or the next 20 info-bits for updating the Agena guidance computer. Logic circuits are provided for bit error recognition and temporary storage.

3.6.2 Communication Equipment

A list of equipment to be used in the Agena space tug communication subsystem is presented in Table 3-11. The equipment specified is, in general, qualified as well as flight proven. All the equipment listed, except the power amplifier and command decoder, have flown successfully many times on Agena vehicles. A unit similar to the command decoder listed in Table 3-11 was built by Lockheed for the Gemini Program (six vehicles flown).

From the standpoint of reliability, a preliminary review was made to determine the redundancy requirements for the Agena communications system. The baseband assembly unit is already built with internal redundancy, and it is felt that the transmitter receiver/demodulator and decoder because they are critical units in the overall success of any mission, should also be redundant.

Only one PCM telemeter will be flown. The most probable failure mode in this unit is the shorting or opening of a data gate; however, critical monitors can be connected in parallel so that any single gate failure will not result in the loss of the data from that monitor.

Table 3-11

COMMUNICATION SUBSYSTEM EQUIPMENT LIST

Title	Part No.	Spec No.	Power (watts)	Weight (lb)	Qualified	Vendor
PCM Telemeter Type IV	1460965	1420766	7	4	Yes	S. C. I.
TLM J-Box	1386098	1420836	1	5.2	Yes	LMSC
Baseband Assy Unit	1462590	1420953	2	4.4	Yes	Motorola
Transmitter, 2 watt	1462031	1419277	34	7.3	Yes	Motorola
Power Amplifier	CTA-402-20	–	60	1.9	No	Conic
Multicoupler, Type 14	1462232	1419745	–	2.2	Yes	Wavecom
Antenna Type 28	1387523	1420990	–	1.8	Yes	LMSC
RF Switch, Type 14	1462071	1419552	16	0.6	Yes	Transco
Receiver UHF-PM	1462033	1416750	8	6.2	Yes	Motorola
Command Decoder	–	–	5	3	No	LMSC
Parabolic Antenna	–	–	–	12	Yes	LMSC

Section 4
INTERFACE DESCRIPTION

Section 4
INTERFACE DESCRIPTION

This description of the interface between the Agena tug and the shuttle orbiter when the Agena is used as an expendable upper stage to the space transportation system follows the Agena tug configuration description of Sections 2 and 3.

Constraints imposed on the installation of the Agena in the orbiter cargo bay are discussed; then the Agena/payload support, attachment system, and deployment mechanism are defined. Also defined are the umbilical connections for propellants, electrical power and data management, and the location and function of the Agena service panel.

The weight of the support system, which includes all nondeployable items, was estimated to determine the total shuttle payload weight. Finally, the requirements imposed upon the shuttle system design as a result of integrating the Agena with the orbiter design are summarized.

An artist's conception of the Agena installed in the cargo bay is shown in Fig. 4-1.

4.1 LOCATION OF AGENA IN CARGO BAY

4.1.1 Roll Orientation

The Agena coordinate system is illustrated in Fig. 4-2. The Agena normally flies with the +Z-axis pointed to the earth and the +X-axis in the thrust direction. The propellant fill lines and the electrical umbilical connection are located on the +Y-side of the vehicle. Figure 4-3 is a section through the forward equipment rack, looking forward along the +X-axis, which shows that the inertial reference assembly is located on the vehicle +Z-axis and the guidance computer is on the -Z-axis.

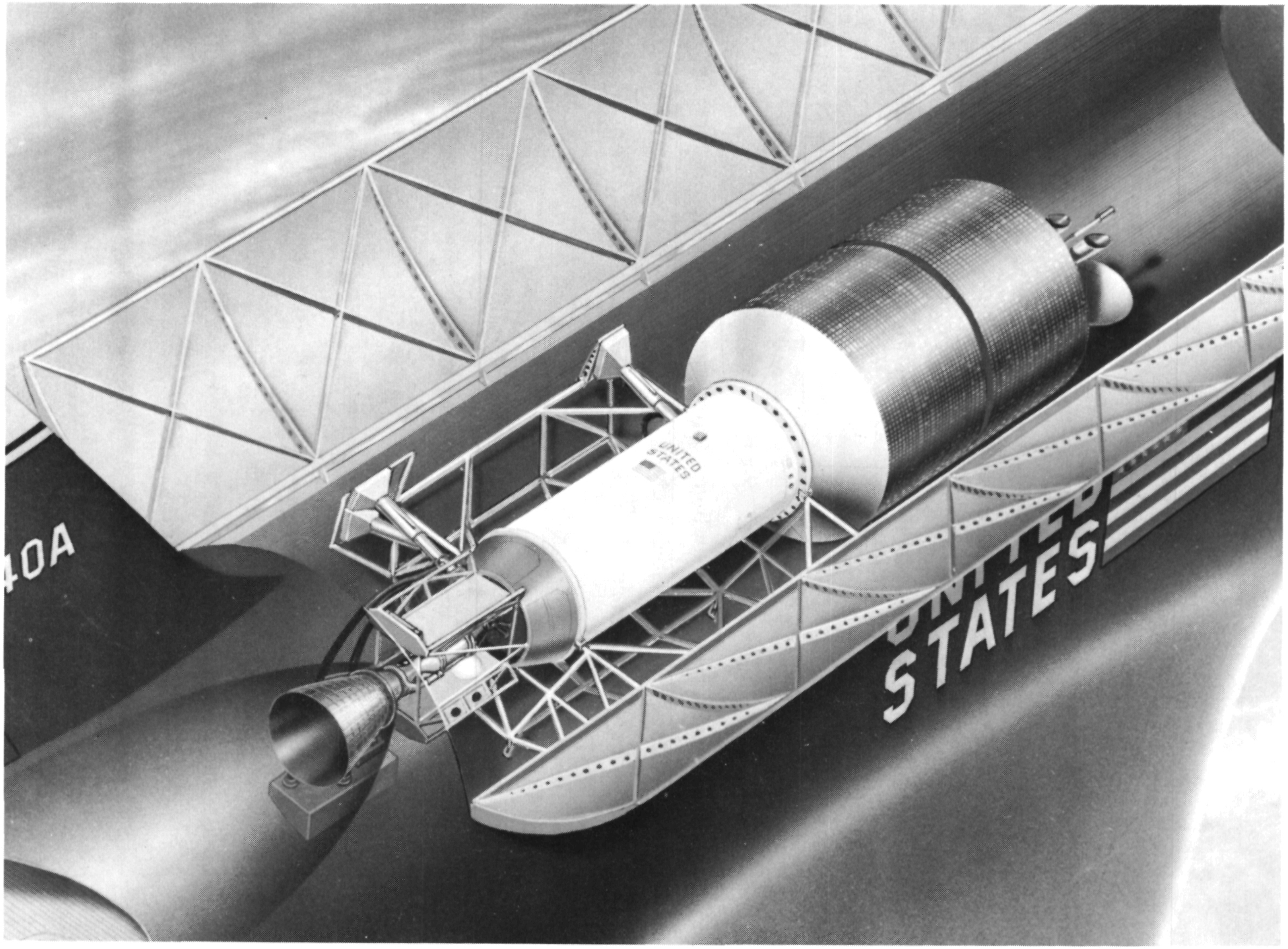


Fig. 4-1 Agena Tug Installed in Orbiter Cargo Bay

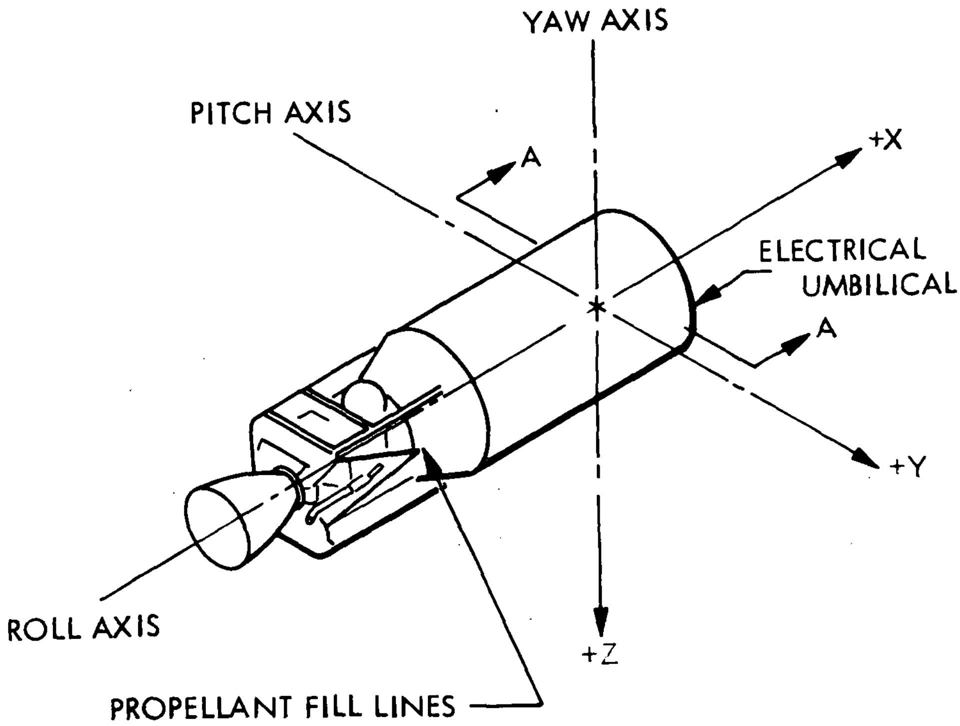


Fig. 4-2 Agena Coordinate System

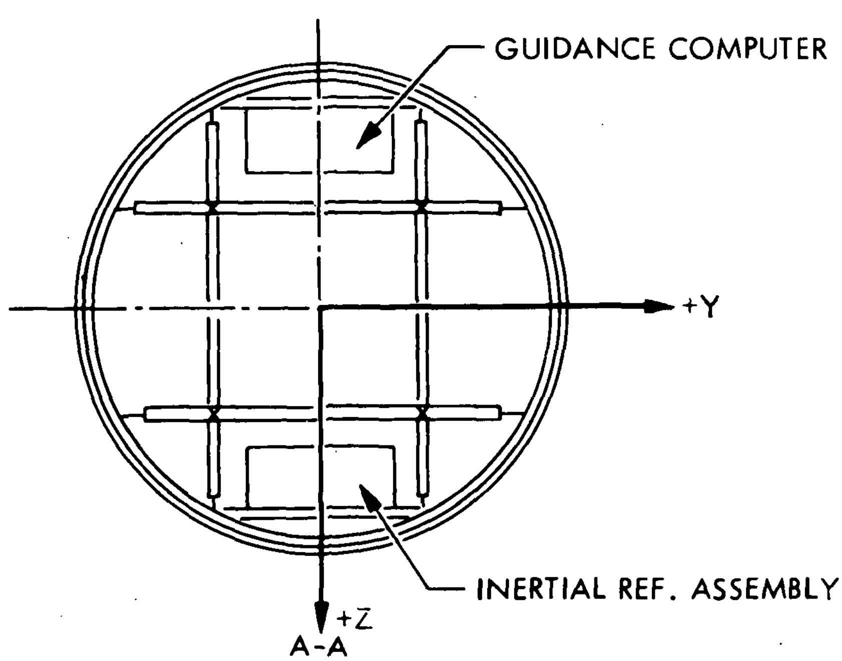


Fig. 4-3 Agena Equipment Section Forward View

To utilize an optical arrangement that will determine the azimuth orientation of the inertial reference assembly before launch, it will be necessary to install the Agena so that an external optical beam can reach this unit. This means that the inertial reference assembly must be facing the cargo bay doors.

It will also be advantageous to locate the guidance computer as deeply as possible within the cargo bay, where the temperature excursion during the ascent flight will be minimum. Both these requirements can be satisfied by relocating these units within the Agena; however, a simpler method is to rotate the Agena 180 degrees about the roll axis, so that the Agena +Z-axis will be pointed to the cargo bay doors. The relation between the Agena coordinate system and the shuttle coordinate system is then shown on Fig. 4-4. The Agena service connections will then be located on the left side of the cargo bay looking forward along the positive X-axis of the shuttle coordinate system.

4.1.2 Longitudinal Location

The longitudinal installation of the Agena and the payload in the cargo bay must satisfy the orbiter longitudinal CG limitations for landing. Figures 4-5, 4-6, and 4-7 show the relationship between the maximum allowable Agena payload weight and payload CG location forward of the Agena interface station for three different Agena locations in the cargo bay. Since landing conditions will exist only for a mission abort case, all Agena propellants will have been dumped. The payload CG diagrams were therefore generated on the basis of an average weight for the empty Agena of 1300 pounds and an Agena/payload support weight of 1500 pounds with CG locations as indicated.

With the Agena located in the most aft position (Fig. 4-5), the payload weight is restricted for payload CG locations within 10 feet of the Agena payload interface station. For payload CG locations of 10 to 14 feet from the Agena, the full capability can be utilized; however, for more forward locations the weight is again restricted by the orbiter CG limitations. Thus, utilizing the full cargo-bay volume and locating the payload CG at the centroid of the remaining volume would limit the weight to approximately 18,000 pounds. For comparison, two typical spacecraft have been included in Fig. 4-5, which shows that these will be marginal for a full aft location.

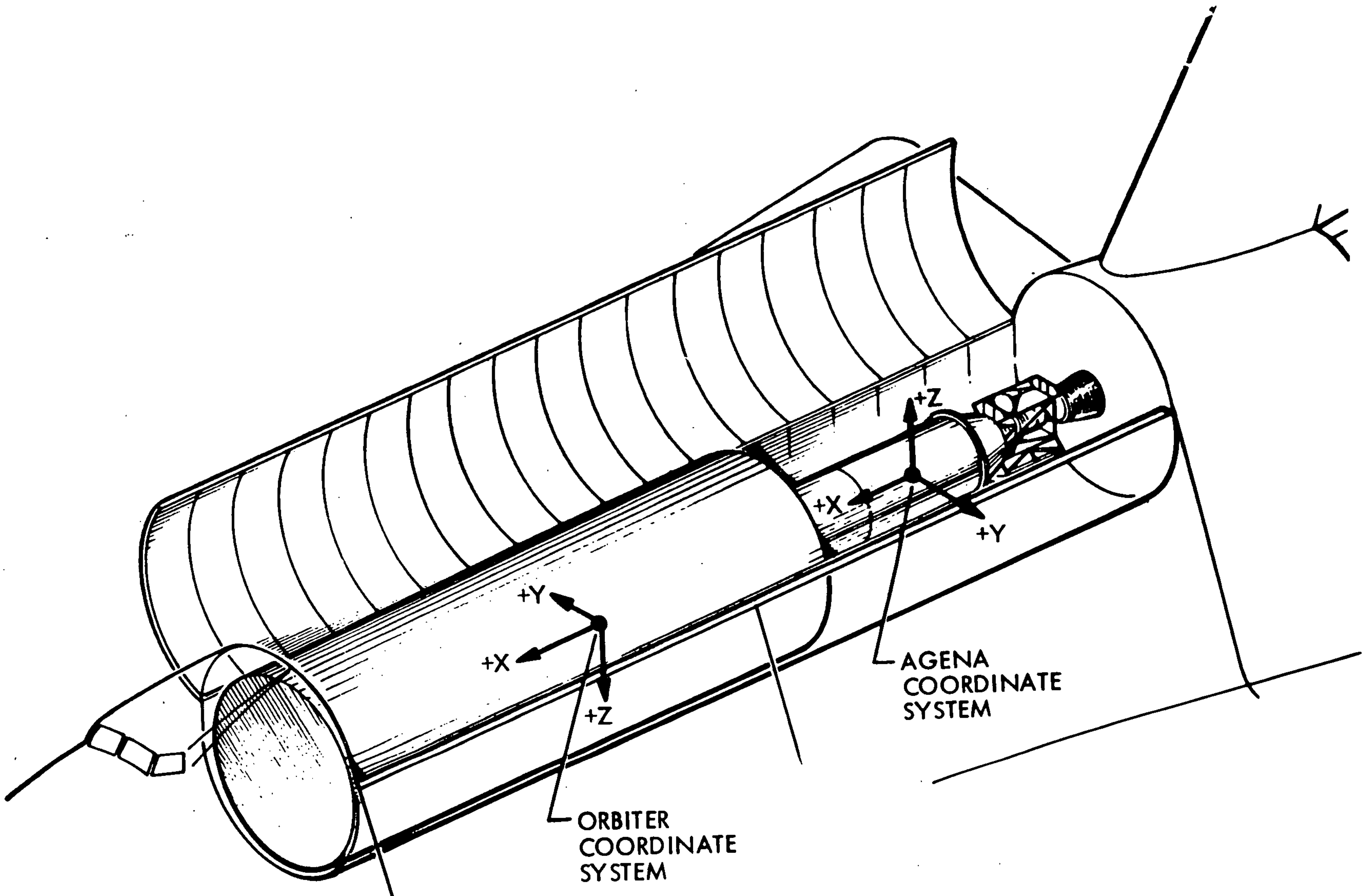


Fig. 4-4 Agena/Shuttle Coordinate Systems

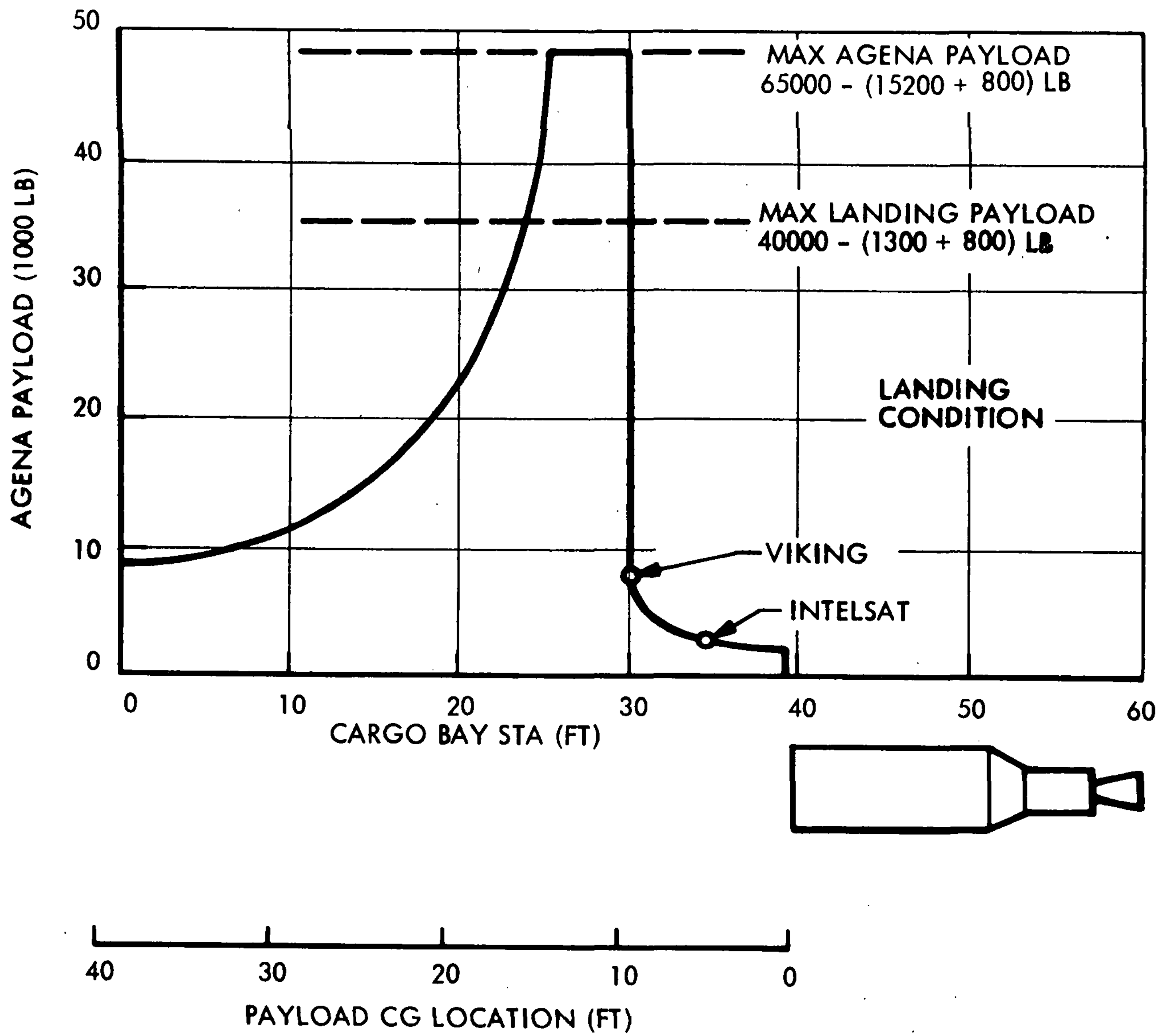


Fig. 4-5 Payload Weight – CG Restriction (Agena in Most Aft Position)

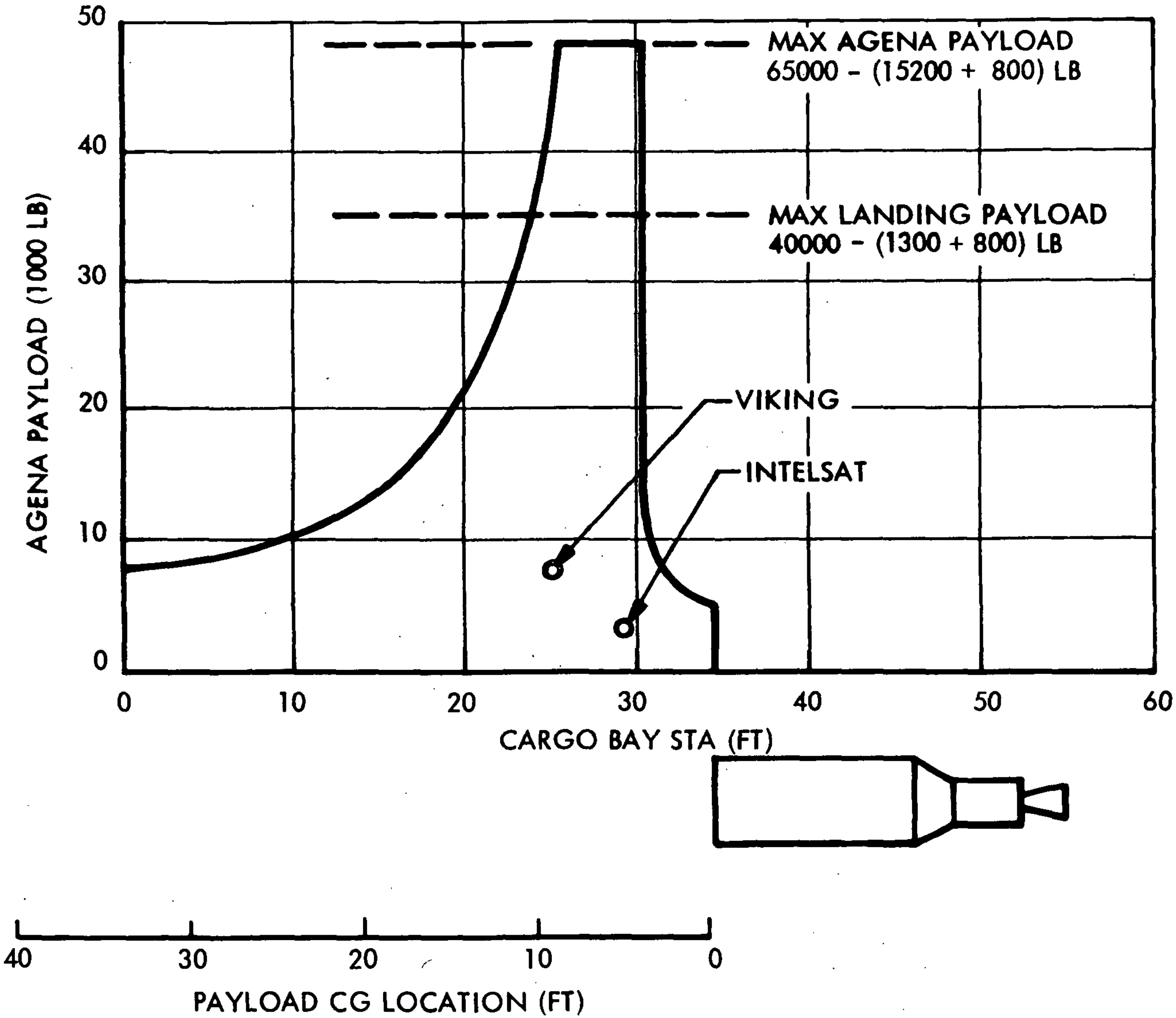


Fig. 4-6 Payload Weight – CG Restriction (Agena Moved Forward 5 ft)

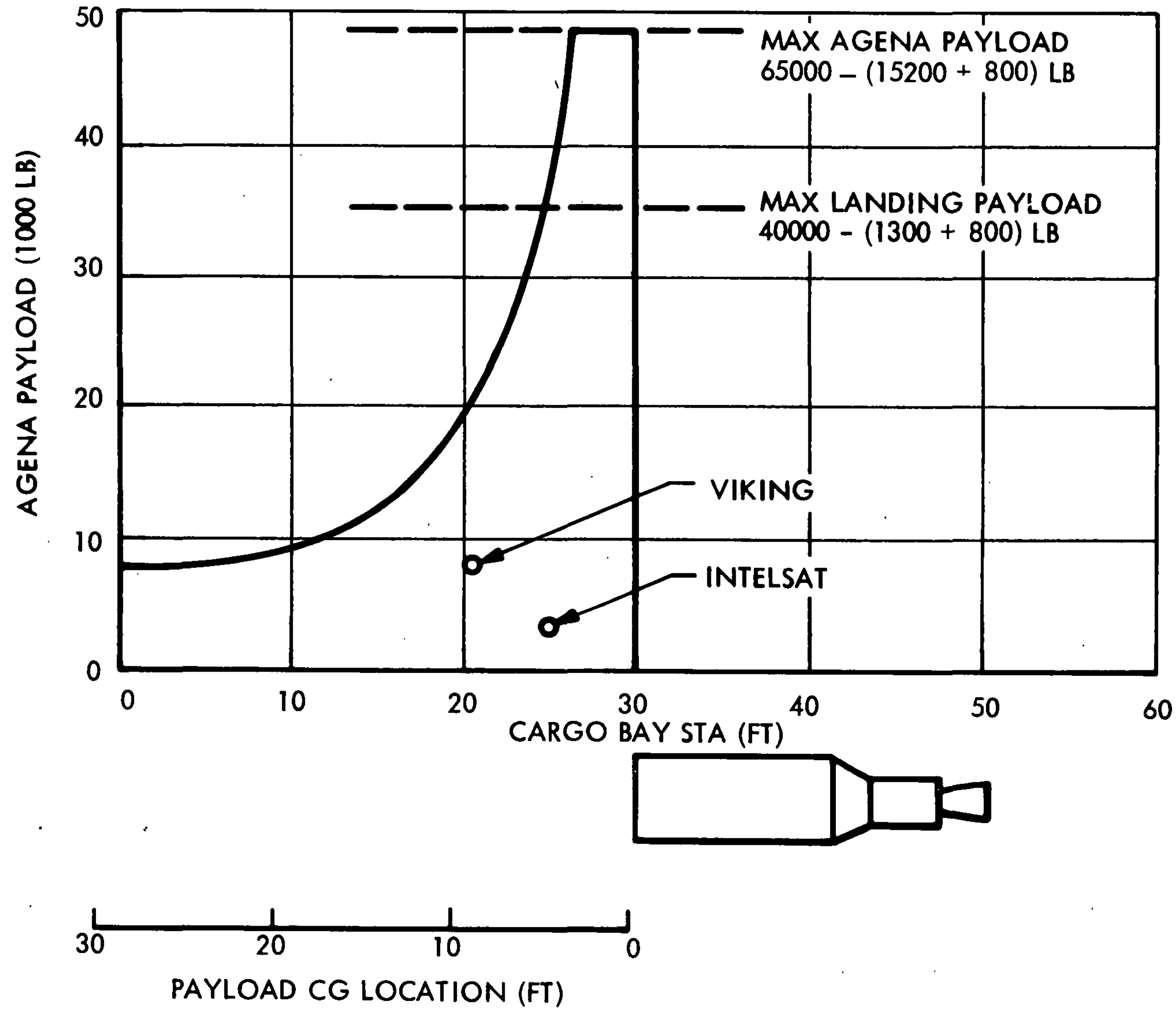


Fig. 4-7 Payload Weight – CG Restriction (Agena Moved Forward 10 ft)

The payload CG constraint can be relieved by moving the Agena forward with respect to the cargo bay. Figure 4-6 shows the same relationship for the Agena moved forward 5 feet from the aft cargo bay bulkhead. In this case a more realistic weight-CG envelope is obtained for smaller payloads and the full capability can be used for CG locations from 4 to 8 feet forward of the Agena. Moving the Agena still farther forward, as shown by Fig. 4-7, will result in the full weight capability between 0- and 4-feet distance from the interface station.

It appears then that the nominal Agena location with the present allowable orbiter CG range will be on the order of 5 feet forward of the most aft location and that this location will be able to accommodate most of the payloads presently planned. This type location does, however, have the disadvantage that the cargo bay volume aft of the Agena will be wasted unless it can be used for other equipment or secondary payloads. The Agena installation must, however, be adjustable to accommodate more extreme payload configurations.

For ascent flight, when the Agena is fully loaded with propellants, no similar CG restriction will exist. However, if for some reason a landing is attempted with all the Agena fuel onboard, the effect is to move the total CG location aft, which could result in orbiter stability and handling problems. It may therefore be advisable to include an extra margin on the aft portion of the CG envelope to provide for this remote possibility.

4.2 UMBILICAL INTERFACE

4.2.1 Agena Service Panel

As discussed previously, it appears that the Agena location may be varied over a maximum distance of 10 feet, depending upon the payload configuration. The nominal position will be the midpoint, 5 feet forward of the aft cargo bay bulkhead. The Agena service panel must be located in such a way that the umbilical connections will be as short as possible and that the panel does not interfere with the installation of the Agena and the support structure for any Agena location within the 10-feet adjustment distance. Furthermore, since the service panel has electrical connections and propellant dump lines

connected on the orbiter side it will be advantageous to have this panel at a fixed location for all missions. As discussed in par. 3.3, the umbilical retract mechanisms will be mounted to the Agena support structure. This arrangement has the advantage of simplifying the service panel and maintaining the panel in a fixed location for all missions. The recommended location of the service panel is shown in Fig. 4-8.

All Agena/orbiter interface connections will be concentrated at the Agena service panel, which will serve as a junction and distribution box for the various electrical connections. Also, the propellant dump lines will go through the service panel, which will serve as a coupling point between the fixed installed pipelines within the orbiter structure and the flexible hoses which connect to the Agena.

A functional block diagram of the service panel (Fig. 4-9) shows all the connections coming into the panel from the orbiter subsystems and all the connections to the Agena/payload and to the Agena support system. Figure 4-10 shows how the service panel can be arranged physically, and a list of plug functions is included in Table 4-1.

The service panel is an Agena-supplied item, together with the umbilical connections and the umbilical retraction mechanisms. All connections on the orbiter side of the panel may be fixed, installed equipment, even though the wires and pipelines may be charged to the Agena system weight. Since all umbilical connections can be disconnected at the service panel, it would be advantageous to leave the panel installed in the orbiter as fixed equipment, even though other types of payloads are flown. In this case it would be advisable to have the panel flush mounted with the orbiter cargo bay skinline to avoid possible interference with other payloads.

4.2.2 Umbilical Connections

4.2.2.1 Propellants. The Agena will be tanked prior to installation in the orbiter cargo bay, simplifying the tanking operation and also the fluid interface between the orbiter and the Agena.

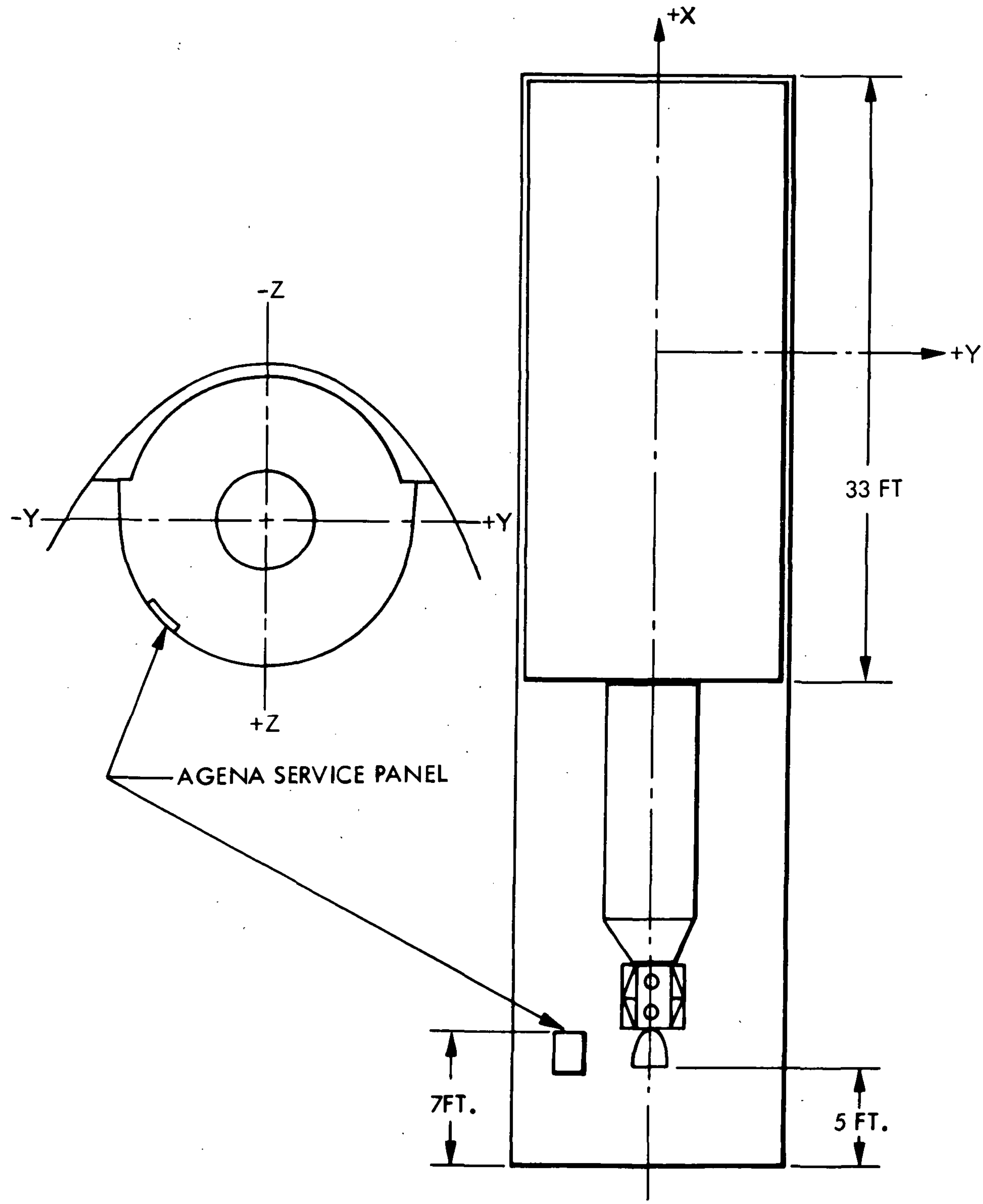


Fig. 4-8 Nominal Agena Location

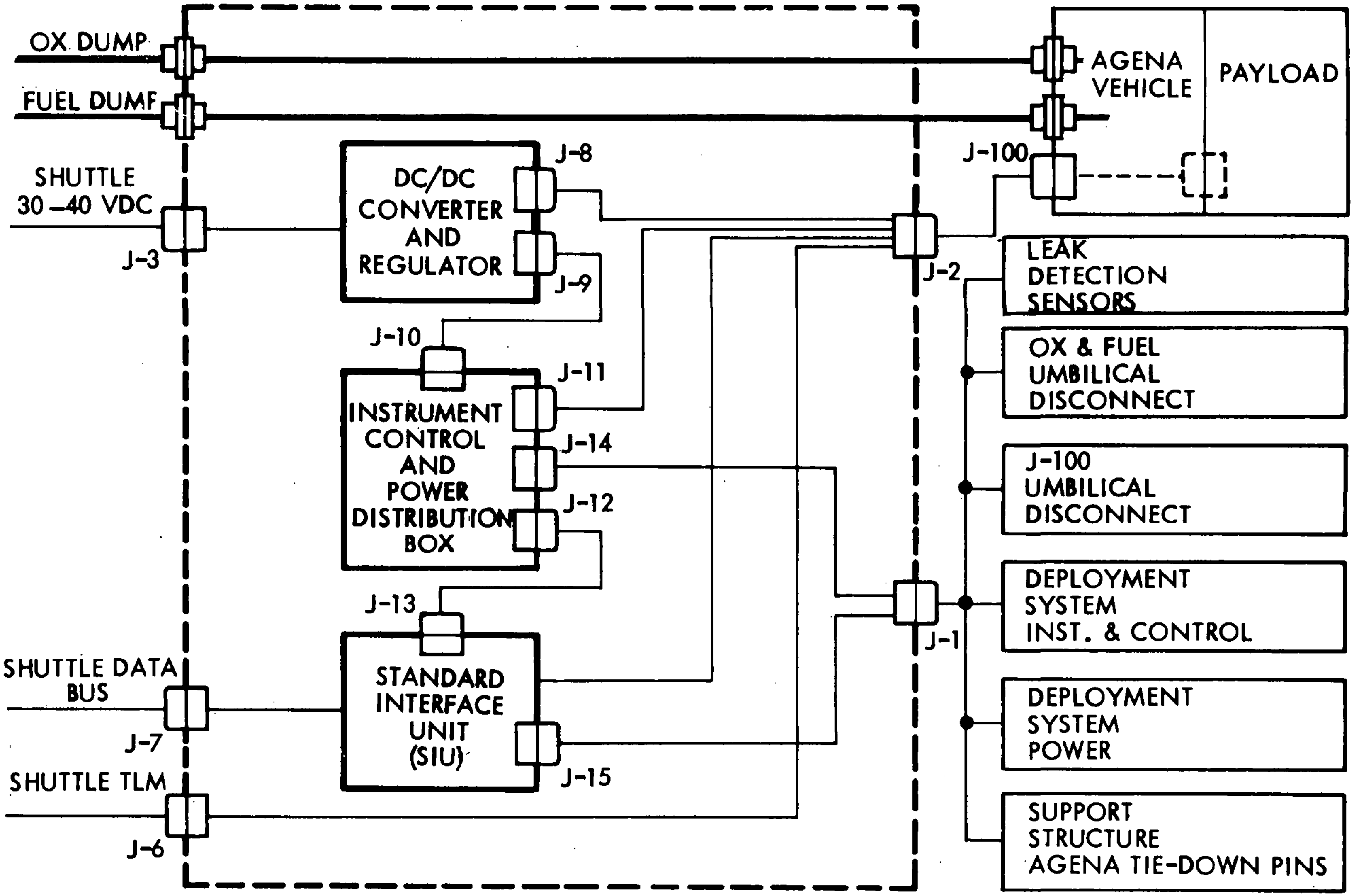


Fig. 4-9 Agena/Payload Service Panel Schematic

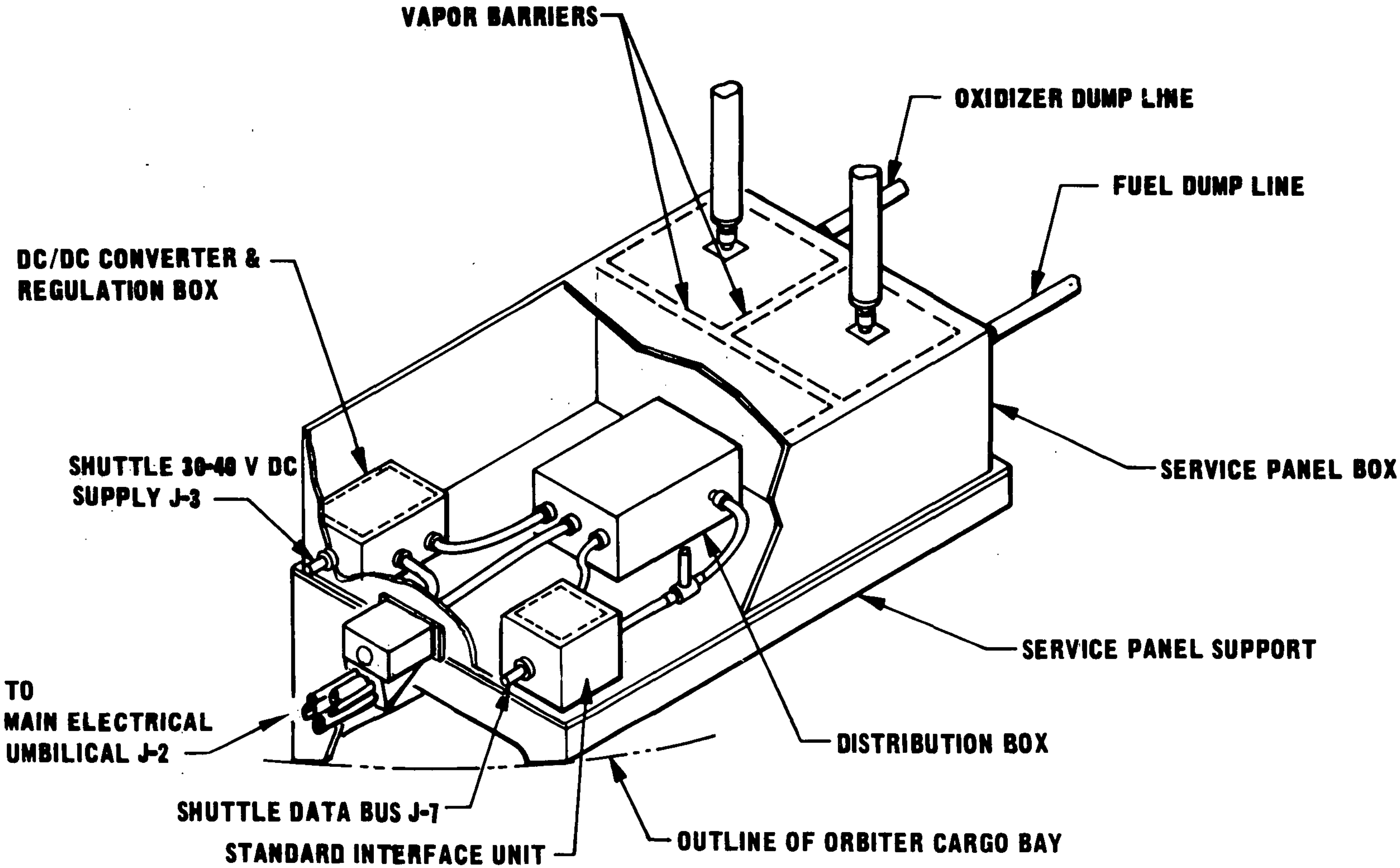


Fig. 4-10 Agena/Payload Service Panel

Table 4-1

PRELIMINARY PLUG LIST, AGENA/PAYLOAD SERVICE PANEL

Plug J-1	Function
1	Leak Detection Sensor Power
2	Leak Detection Sensor Power Return
3	Cargo Bay Vent Oxygen-Leak Sensor
4	Cargo Bay Vent Oxygen-Leak Sensor Return
5	Cargo Bay Vent Fuel Leak Sensor
6	Aft Oxygen-Leak Sensor
7	Aft Oxygen-Leak Sensor Return
8	Aft Fuel Leak Sensor
9	Oxidizer Umbilical Disconnect Control
10	Oxidizer Umbilical Disconnect Control Return
11	Fuel Umbilical Disconnect Control
12	Fuel Umbilical Disconnect Control Return
13	J-100 Umbilical Disconnect Control
14	J-100 Umbilical Disconnect Control Return
15	Agena Tiedown Pin Control
16	Agena Tiedown Pin Control Return
17	Agena Tiedown Pin No. 1 Sensor
18	Agena Tiedown Pin No. 2 Sensor
19	Agena Tiedown Pin No. 3 Sensor
20	Agena Tiedown Pin No. 4 Sensor
21	Agena Tiedown Pin Sensor Return
22	Deployment System Power
23	Deployment System Power Return
24	Spar Boom No. 1 Control
25	Spar Boom No. 2 Control
26	Spar Boom No. 3 Control
27	Spar Boom No. 4 Control
28	Spar Boom Control Return
29	Oxygen Umbilical Disconnect Sensor
30	Fuel Umbilical Disconnect Sensor
31	J-100 Umbilical Disconnect Sensor
32	Cargo Bay Temperature
33	Boom No. 1 Extension Rate
34	Boom No. 2 Extension Rate
35	Boom No. 3 Extension Rate
36	Boom No. 4 Extension Rate
37	Boom Extension Rate Return

Plug J-2	Function
	Same as J-100 Pin List (Par. 6.5)

Plug J-3	Function
1	Shuttle EPS Power
2	Shuttle EPS Power Return

Table 4-1 (cont)

Plug J-6	Function
	PCM Type IV (Coaxial Cable)

Plug J-7	Function
1	Shuttle Data Bus No. 1
2	Shuttle Data Bus No. 1 Return
3	Shuttle Data Bus No. 2
4	Shuttle Data Bus No. 2 Return
5	Shield

Plug J-8	Function
1	Agena 28 VDC Regulator
2	Agena 28 VDC Regulator Return
3	Payload 28 VDC Regulator
4	Payload 28 VDC Regulator Return

Plug J-9	Function
1	Service Panel 28 VDC Regulator
2	Service Panel 28 VDC Regulator Return

Plug J-10	Function
1	Service Panel 28 VDC Regulator
2	Service Panel 28 VDC Regulator Return

Plug J-11	Function
1	Agena Power On Control
2	Agena Power Off Control
3	Payload Power On Control
4	Payload Power Off Control
5	Oxidizer PIV Dump On Control
6	Oxidizer PIV Dump Off Control
7	Fuel PIV Dump On Control
8	Fuel PIV Dump Off Control
9	Pressurization Dump Valve On Control
10	Pressurization Dump Valve Off Control

Table 4-1 (cont)

Plug J-12	Function
1	Agena Internal/External Power On Control
2	Agena Internal/External Power On Control Return
3	Payload Internal/External Power On Control
4	Payload Internal/External Power On Control Return
5	Oxidizer PIV Dump On Control
6	Oxidizer PIV Dump Off Control
7	Fuel PIV Dump On Control
8	Fuel PIV Dump Off Control
9	Pressurization Dump Valve On Control
10	Pressurization Dump Valve Off Control
11	Oxidizer Umbilical Disconnect Control
12	Oxidizer Umbilical Disconnect Control Return
13	Fuel Umbilical Disconnect Control
14	Fuel Umbilical Disconnect Control Return
15	J-100 Umbilical Disconnect Control
16	J-100 Umbilical Disconnect Control Return
17	Agena Tiedown Pin Control
18	Agena Tiedown Pin Control Return
19	Deployment System Power
20	Deployment Systems Power Return
21	Spar Boom No. 1 Control
22	Spar Boom No. 2 Control
23	Spar Boom No. 3 Control
24	Spar Boom No. 4 Control
25	Spar Boom Control Return

Plug J-13	Function
	(Same as J-12)

Plug J-14	Function
	Power for J15 functions

Plug J-15	Function
1	Cargo Bay Vent Oxygen Leak Sensor
2	Cargo Bay Vent Oxygen Leak Sensor Return
3	Cargo Bay Vent Fuel Leak Sensor
4	Cargo Bay Vent Fuel Leak Sensor Return
5	Aft Oxygen Leak Sensor
6	Aft Oxygen Leak Sensor Return
7	Aft Fuel Leak Sensor
8	Aft Fuel Leak Sensor Return
9	Agena Tiedown Pin No. 1 Sensor
10	Agena Tiedown Pin No. 2 Sensor
11	Agena Tiedown Pin No. 3 Sensor
12	Agena Tiedown Pin No. 4 Sensor
13	Agena Tiedown Pin Sensor Return
14	Oxidizer Umbilical Disconnect Sensor
15	Fuel Umbilical Disconnect Sensor
16	J-100 Umbilical Disconnect Sensor

The design requirement for propellant dumping in case of a mission abort does, however, require that two dump lines be connected between the Agena and the service panel, as shown in Figs. 4-9 and 4-10. These dump lines can be connected to the existing Agena fill couplings and must extend behind the service panel within the orbiter interior to some convenient exit point on the orbiter exterior skin surface. It would be desirable to locate these exit points somewhat apart, preferably one on each side of the fuselage or at the wingtips; however, this is not an absolute design requirement, especially if sequential dumping is possible.

The dump lines will be connected immediately after installation of the tanked Agena into the cargo bay and will remain connected until just before deployment, at which time the retract mechanism with the quick disconnect will be activated. The fluid interface is therefore simple; it will consist of only these two lines and the retraction mechanism. The dump lines will always be dry, except for an abort condition.

This propellant interface can also be used if Agena tanking is required after installation in the cargo bay, by adding fill couplings at the exit points on the orbiter skin surface. However, some modifications to the propellant valve system as presently configured would be necessary.

4.2.2.2 Gases. Helium gas for tank pressurization and nitrogen gas for attitude control will also be loaded prior to Agena installation in the cargo bay. Umbilical connections to these fill couplings will therefore not be required.

4.2.2.3 Electrical Power Supply. During ground operation, ascent flight, and orbit maneuvers prior to deployment, the Agena and the spacecraft will receive electrical power from the orbiter power supply system. An umbilical connection for this purpose will therefore be required.

All electrical connections to the Agena and the spacecraft go through the main electrical umbilical (J-100) located near Station 247 on the Agena vehicle +Y-axis. A retract and disconnect coupling will be located on the Agena support structure and the cable will be routed along the support structure to the Agena service panel. This disconnect will be activated at the time of switchover to Agena internal power.

The Agena operates on 28 VDC power, while the shuttle delivers a nominal 34-volt regulated power with a regulation range of 30 to 40 volts. A power conditioning unit will therefore be required to convert the shuttle power to 28 VDC. This unit will be located at the Agena service panel, as shown by the schematic diagram (Fig. 4-9).

The service panel will provide a disconnect point at J-2. A cable will be required from the service panel (J-3) to the nearest power supply point in the orbiter assumed to be at the forward bulkhead of the cargo bay. This cable is included in the Agena support weight.

4.2.2.4 Data Management. The orbiter/Agena data management and information transfer interface is also shown on the schematic diagram of the Agena service panel (Fig. 4-9). It is presently anticipated that the orbiter data management system will perform all the Agena and payload checkout and monitoring functions prior to deployment, requiring a number of hardline connections between the orbiter and the Agena. As previously mentioned, all of the Agena electrical connections go through the electrical umbilical plug, J-100. It is also assumed that the payload will be interfaced with the orbiter through the J-100 connection point. The J-100 connector contains 110 pins and four coaxial cables. The expected connections to this point are listed in Table 4-2, which shows that the Agena will utilize a total of 75 pins, leaving 35 pins available for the spacecraft functions. Plug J-2 on the service panel will also contain the same pin assignment.

All the Agena/spacecraft monitors will be processed through the standard interface unit, which is located in the Agena service panel and relayed to the orbiter computer and display equipment via the orbiter data bus at a rate of 25 kbps. The Agena telemetry output of 62.5 kbps is sent directly to the shuttle TM encoder and to the ground on the high rate downlink. The Agena command and guidance update data will be transmitted to the Agena via the data bus and the standard interface unit. The commands will enter the Agena system via the proper pins in the J-100 connector.

Table 4-2

J-100 PIN FUNCTION LIST

1	Agena Internal Power On Control	40	Step Return
2	Agena Internal Power Off Control	41	Start
3	Agena Internal Power ON/OFF Monitor	42	ISA On Monitor
4	Agena Battery Current Monitor	43	ISA On Return
5	S3-S4 Test Control	44	Transmitter No. 1 Temperature
6	Current Monitor Return	45	Transmitter No. 2 Temperature
7	Main Bus Volt Monitor	46	Transmitter No. 1 ON-OFF
8	Volt Monitor Return	47	Transmitter No. 2 ON-OFF
9	Agena External Power	48	BBAU No. 1 ON-OFF
10	Agena External Power Return	49	BBAU No. 2 ON-OFF
11	Disable Gas Valves	50	Decoder No. 1/2 Command Output
12	Helium Temperature Monitor	51	Decoder No. 1 ON-OFF
13	Nitrogen Temperature Monitor	52	Decoder No. 1 ON-OFF
14	Clear to Send	53	Receiver No. 1 ON-OFF
15	Clear to Send Return	54	Receiver No. 2 ON-OFF
16	Idle Command	55	Power Amplifier No. 1 Temperature
17	Idle Command Return	56	Power Amplifier No. 2 Temperature
18	Load Command	57	TT&C Monitor Return
19	Load Command Return	58	TT&C ON Control
20	Utility Discrete	59	TT&C OFF Control
21	Enable Inputs	60	Fuel Tank Pressure
22	Halt	61	Oxidizer Tank Pressure
23	GC Common Return	62	Fuel Tank Temperature
24	GC Common Return	63	Oxidizer Tank Temperature
25	Read Command	64	Tank Temperature Return
26	Read Command Return	65	Payload Internal Power ON Control
27	Ready/Busy	66	Payload Internal Power OFF Control
28	Ready/Busy Return	67	Oxidizer PIV Dump-ON Control
29	Serial Data From Computer	68	Oxidizer PIV Dump-OFF Control
30	Serial Data Return	69	Fuel PIV Dump ON Control
31	Serial Data From PSE	70	Fuel PIV Dump-OFF Control
32	Serial Data Return	71	Pressure Dump Valve-ON Control
33	Shift Clock	72	Pressure Dump Valve-OFF Control
34	Shift Clock Return	73	Oxidizer PIV Monitor
35	GC Common Return	74	Fuel PIV Monitor
36	Serial Register Loaded	75	Dump Valve Monitor
37	Serial Register Return	76	Payload External Power
38	GC Common Return	77	Payload External Power Return
39	Step	78	Payload Internal Power ON/OFF Monitor

4.2.3 Safety Sensors

A limited number of safety sensors such as fuel and oxidizer leak detectors and cargo-bay temperature will be mounted at appropriate locations on the Agena support structure rather than on the Agena vehicle itself, which will simplify the Agena interface. The sensors and the corresponding cabling will be a nonrecurring cost item, and the Agena vehicle weight will be reduced.

The connections to these sensors will go through Plug J-1 in the Agena service panel. The output will be fed to the orbiter data system via the standard interface unit and the data bus as shown on the schematic diagram of Fig. 4-9. The connectors pins for these sensors are listed under Plug J-1 in Table 4-1.

4.2.4 Deployment Command and Control

Command signals for operating the umbilical disconnect and retraction mechanism, Agena deployment actuators, and Agena tiedown pin latches will be routed through Plug J-1 in the Agena service panel. These commands may be generated from the mission specialist console by manual operation or by the orbiter control system as part of a payload deployment subroutine. J-1 pin assignments are listed in Table 4-1. The commands will be transferred to the Agena support system via the orbiter data bus and the standard interface unit.

A number of sensors are included in the support system to verify proper operation of the umbilical disconnects and retraction mechanisms, the deployment actuators, and the tiedown releases. The output of these sensors will also enter the orbiter data system via Plug J-1 in the service panel, the standard interface unit and the data bus, as shown by the schematic diagram of Fig. 4-9 and will be displayed on the Agena control console for direct verification of proper operation. The sensors included for this purpose are listed under the pin assignment for Plug J-1 in Table 4-1.

4.2.5 Umbilical Disconnect and Retraction Mechanisms

The umbilical disconnect and retraction mechanisms for the main electrical connector and the propellant dump lines are mounted directly on the support cradle, thus simplifying and actually eliminating one interface between the Agena and the orbiter.

The mechanisms will be installed, tested, and adjusted at the time the Agena, spacecraft, and support cradle are mated prior to installation in the orbiter. At Agena installation in the orbiter cargo bay the only connections to be made will be to connect the two electrical cables and the two flexible propellant dump lines at the Agena service panel.

The disconnect mechanisms for the propellant dump lines and the electrical connection are similar to those presently used on the launch pad and will require only minor modifications of the existing design.

4.3 AGENA SUPPORT AND DEPLOYMENT SYSTEMS

The method selected for supporting the Agena and payload in the orbiter cargo bay and for deploying them on orbit will depend largely on the payload configuration and weight. To provide the necessary operational flexibility, alternate designs were developed. In all cases the interface with the orbiter was kept as simple and as nearly common as possible.

4.3.1 Support Systems

The support system designs were selected for securing the Agena and payload in the orbiter cargo bay. These designs, described in par. 3.1 (Figs. 4-1 and 4-11), will accommodate the range of payload weights and configurations that may be expected for orbital placement by the Agena space tug. On two of the designs (the cantilevered and extended cradle support systems) the orbiter interface is through four attach points-two on the payload bay sides and two on the keelson. A third design (cantilevered support cradle with payload adapter) interfaces through four attach points, all of which are on the cargo bay sides (Fig. 4-12).

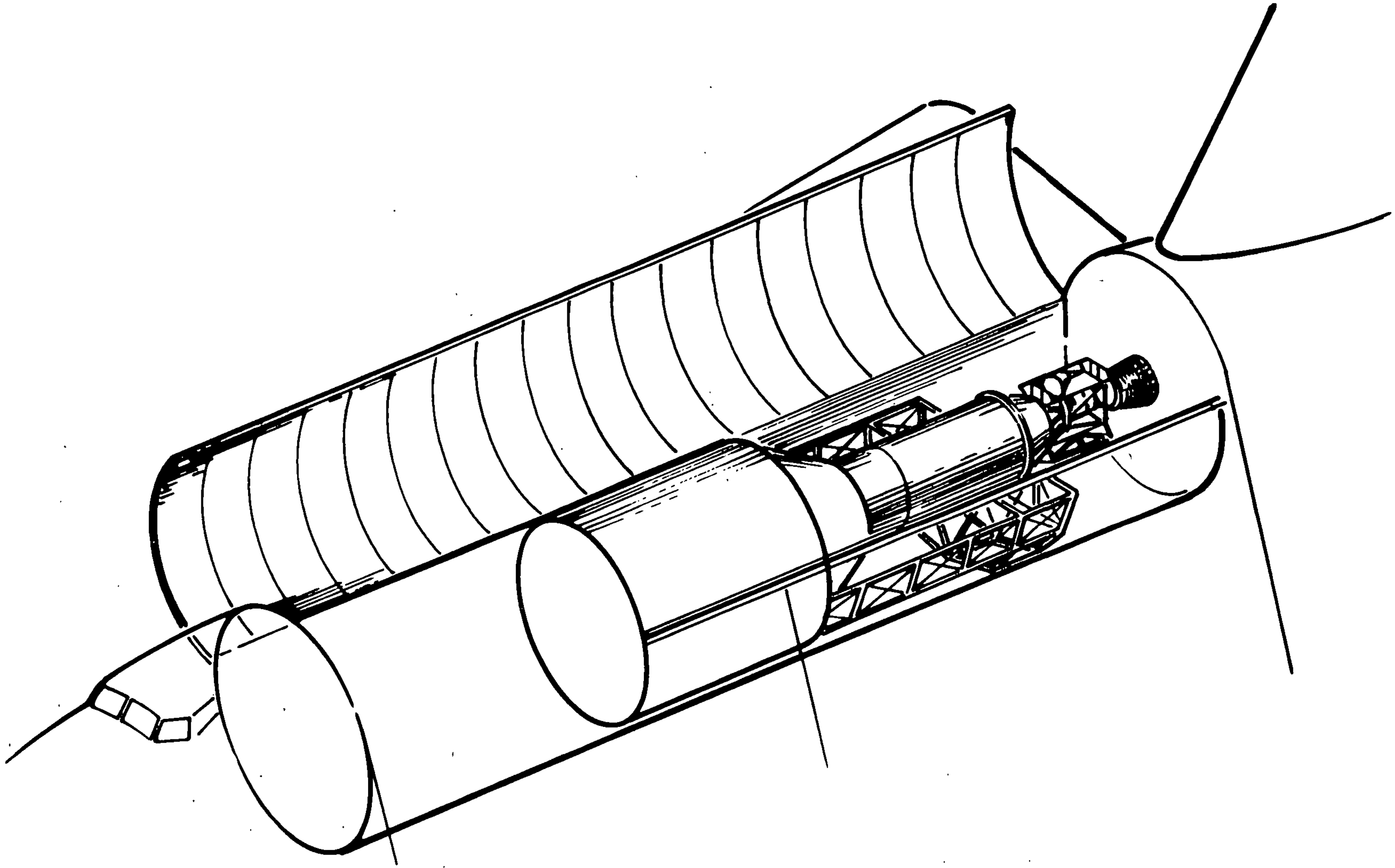


Fig. 4-11 Cantilevered Support With Payload Adapter

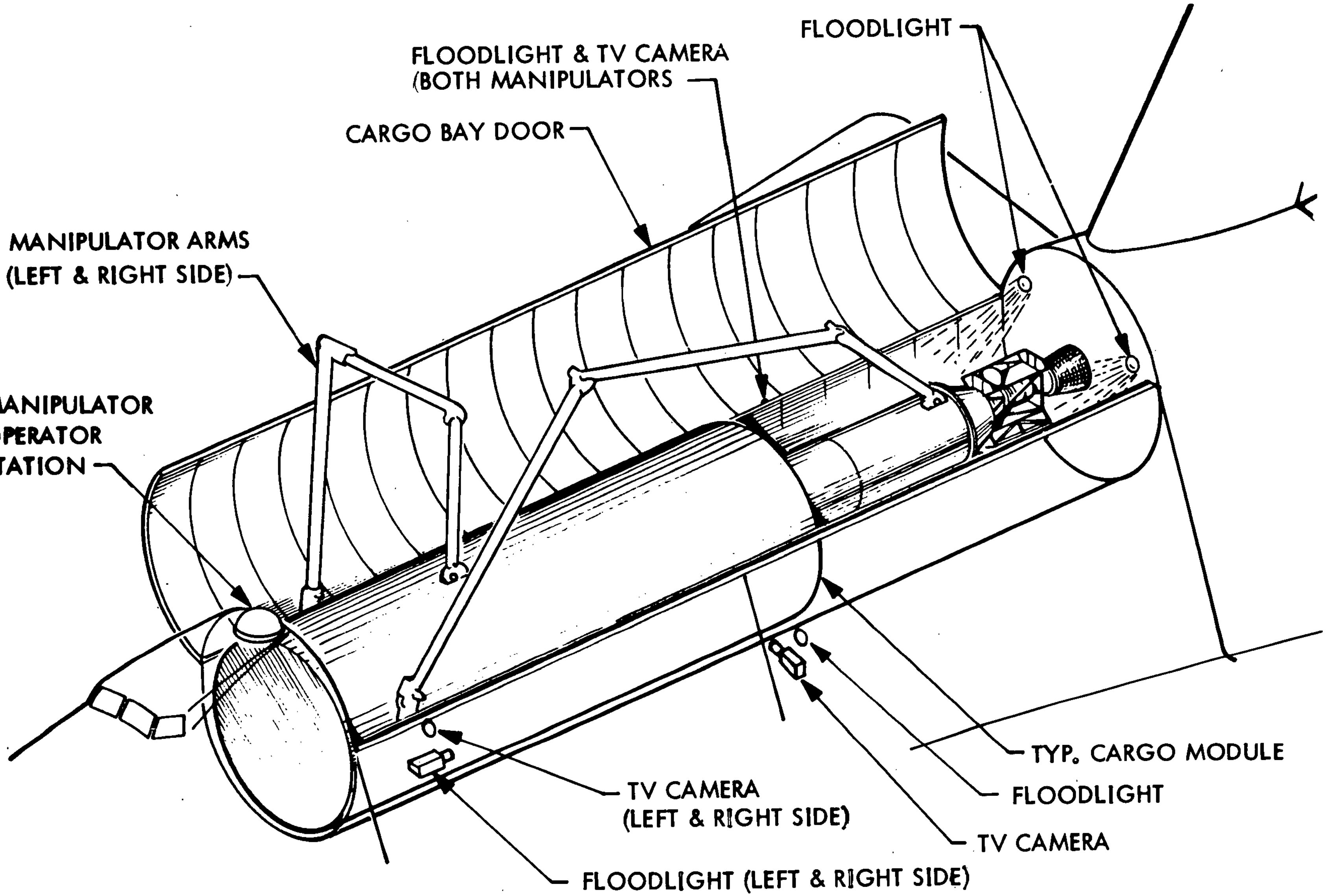


Fig. 4-12 Deployment Systems, Remote Manipulators

4.3.2 Interface Structure Loads

Interface load components are covered in par. 3.1.5 of this document.

4.3.3 Deployment Mechanisms

The Agena/payload configuration can be deployed from the cargo bay by use of either the remote manipulator system or extendible booms, as described in the following paragraphs.

4.3.3.1 Remote Manipulator System. Use of the orbiter remote manipulator system for deployment of the Agena and its attached payload is discussed in par. 3.1 and is shown in Fig. 4-12. Fittings for grasping will be included on the structural ring, which will be added to the Agena at Station 384, and another grasping point will be incorporated with the spacecraft design. For maximum maneuvering stability these two grasping points should be located as far apart as possible. The manipulator arms will be attached to the grasping points prior to Agena umbilical release. The fittings are designed to resist forces in all three axes.

4.3.3.2 Extendible Booms. An alternate deployment system (Fig. 4-13) uses four bi-STEM boom devices, permanently attached to the support truss adjacent to the Agena/payload support points. The extendible portion of the boom is attached to the Agena/payload with off-center latches, which will be opened prior to pulling the main attaching pins. Electrical motors will be actuated to drive the bi-STEM booms from the storage spools, and the motors will be synchronized to ensure that each of the four booms is extending at the same rate. Deployment velocities of 2 to 4 feet per second can be achieved with this system.

The extendible boom method offers ease of operation and simplicity and can be used for all types of payload configurations and for the three types of support systems discussed in par. 3.1. Since the boom mechanisms and motors are attached to the support structure, they will be nonrecurring cost items and are not included in the Agena vehicle weight.

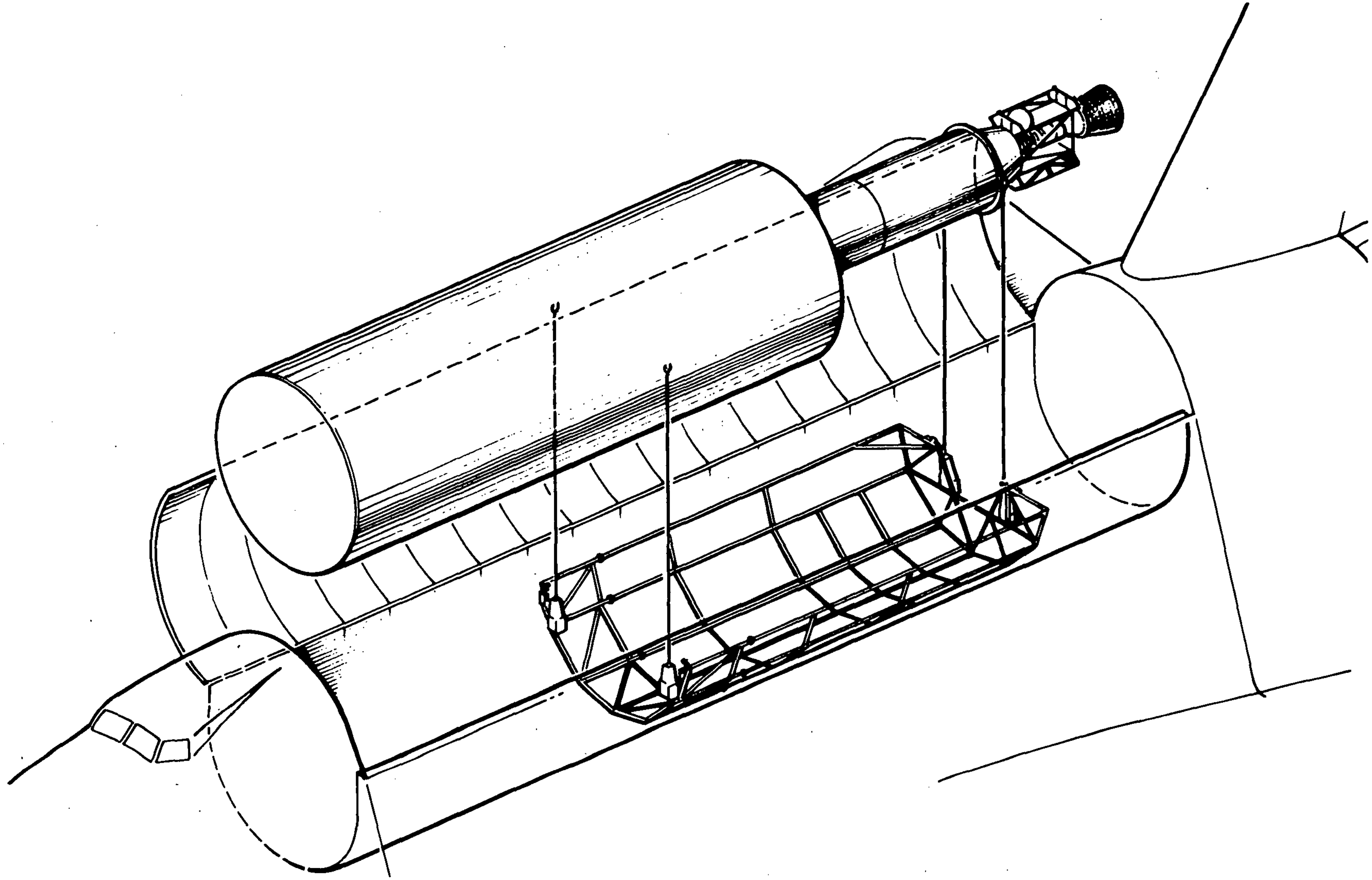


Fig. 4-13 Alternate Agena Deployment System

4.4 GUIDANCE SYSTEM INTERFACE

Three guidance system interfaces with the orbiter are visualized at this time:

a. A link between the AGS computer and the shuttle to allow interrogation and update of the AGS computer.

b. A 4 kbps data link from Agena to shuttle, for realtime display on board the shuttle.

c. A 64.5 kbps link that would permit the shuttle to relay Agena telemetry to the ground.

If high-accuracy azimuth alignment is required, an optical interface with the launch facility will also be involved.

4.4.1 Agena Guidance System Update

The Agena guidance system can accept commands and be updated prior to deployment in the shuttle orbit. The data will be transmitted via the orbiter data bus, the standard interface unit, and the umbilical connection, J-100. Although the Agena guidance system will perform its own navigation and orbit determination during ascent to shuttle orbit, it is assumed that agreement between the Agena and orbiter guidance system will be verified before deployment. The Agena guidance data can be updated with respect to state vector during system checkout if the Agena system data are felt to be less accurate.

The following requirements will be imposed on data transfer from the orbiter computer to the Agena computer:

a.	Format:	20-bit words, transferred sequentially; logical 1 = 5V +0.5V logical zero = 2.5V
b.	Maximum Bit Rate:	Up to 1 million bits per second
c.	Minimum Bit Rate:	N/A
d.	Minimum Spacing Between Words:	0.15 msec (could be reduced to 0.02 msec by AGS software modification, if desirable)
e.	Maximum Spacing Between Words:	N/A

4.4.2 Guidance System Alignment

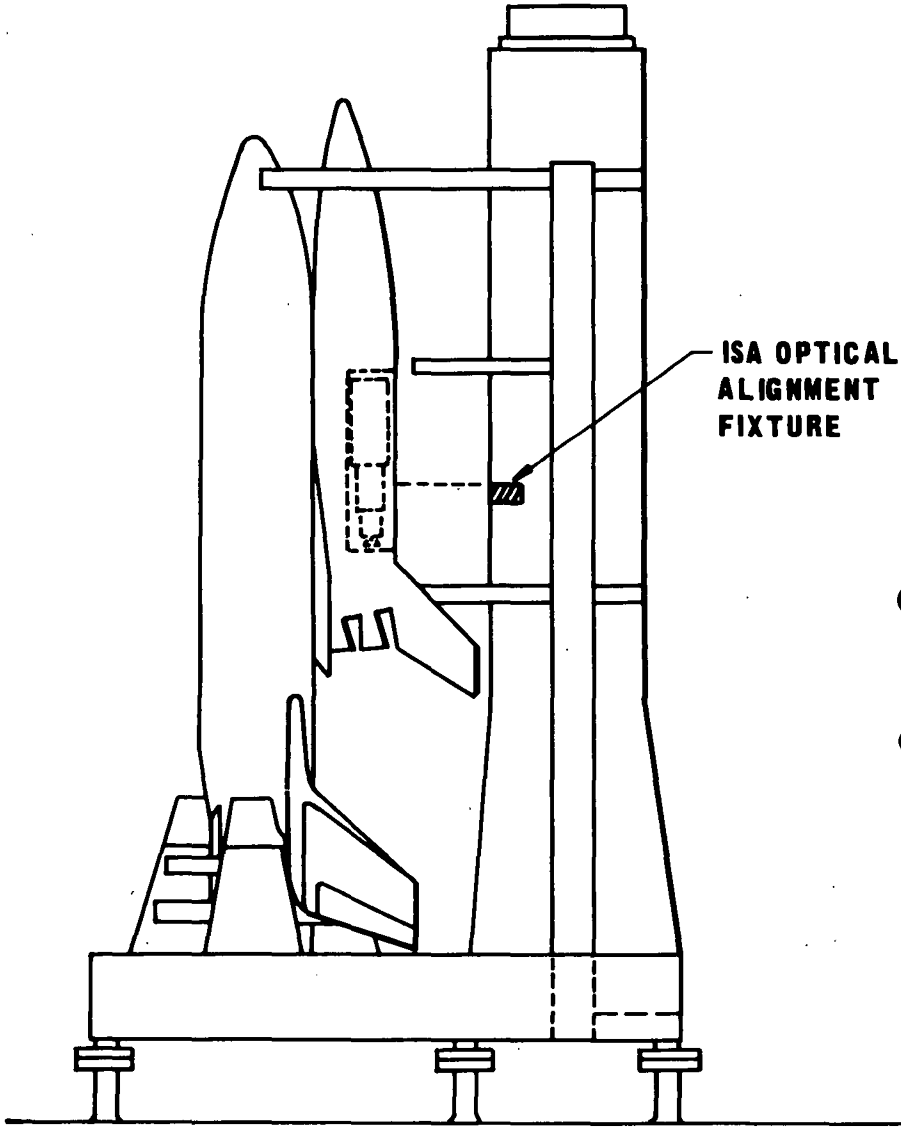
It does not appear that an exact mechanical alignment and adjustment between the Agena and the orbiter will be required. The Agena guidance system will be aligned prior to launch by a flight initialization routine that is a software equivalent of platform leveling and azimuth orientation determination. This method utilizes the earth's gravity field and rotation rate as input data; azimuth orientation is determined by gyro compassing.

After orbit injection the Agena guidance system will be updated with respect to state vector and orbit parameters; however, attitude information will be obtained from the Agena reference package with sufficient accuracy for most missions. For the long-duration mission it may be advantageous to update the Agena attitude data before ignition by means of the onboard horizon sensor unit.

For certain missions it may be desirable to determine the Agena azimuth orientation with a high degree of accuracy before liftoff. This can be done by an external optical alignment device mounted on the launch tower. Software provisions are therefore made for inputting an optically determined azimuth correction during sensor alignment, which can reduce the initial azimuth uncertainty from 30 arc minutes to approximately 3 arc minutes. The optical alignment beam can be introduced either through the open cargo bay doors or through a small window in the doors (Fig. 4-14). Two or three such windows may be required to accommodate the Agena in the different positions in the cargo bay.

4.5 ELECTRICAL POWER SYSTEM INTERFACE

During the period from Agena installation in the cargo bay to deployment on orbit the Agena will require electrical power from the orbiter ground or onboard supply at the rate indicated in Fig. 4-15.



- AGENA OPERATIONS AND DATA ARE HANDLED THRU SHUTTLE DATA BUS AND GROUND COMMUNICATIONS LINKS
- OPTICAL PATH REQUIRED FOR AGENA ASCENT GUIDANCE AZIMUTH ALIGNMENT

Fig. 4-14 Guidance System Alignment

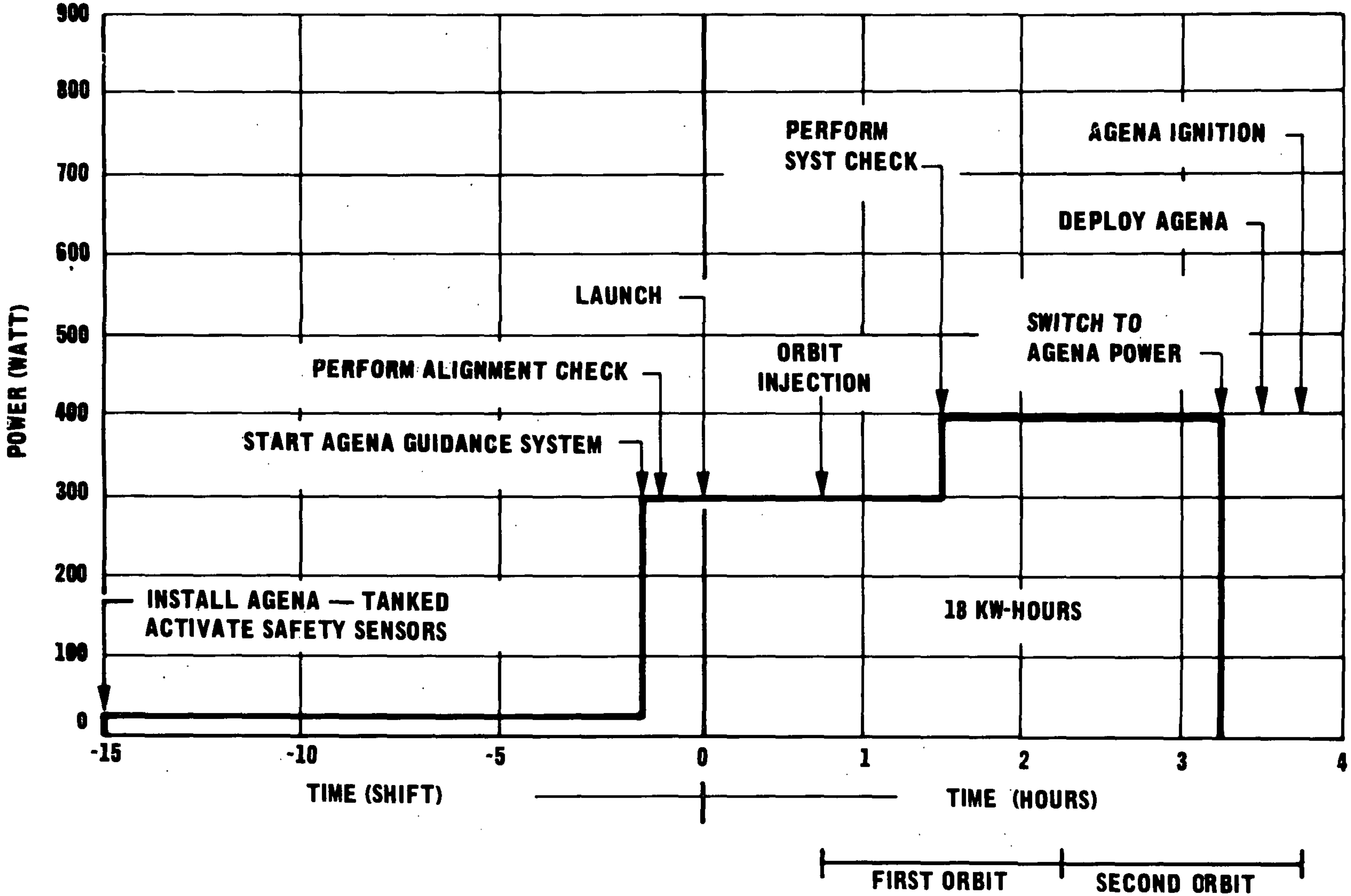


Fig. 4-15 Predeployment Power Requirement

At Agena installation, which could take place at as much as 15 days before launch, the safety sensors will be activated and continuously monitored until the Agena is deployed. The power to drive these sensors will come from the orbiter and the output will be fed directly into the orbiter control system. At 24 hours before launch the Agena guidance system will be activated to align the system; the guidance system will be running continuously from then on. Ascent flight from launch to orbit injection was assumed to be 45 minutes, with the Agena deployed on the second orbital pass. The resulting power profile indicates a total power requirement of 18 kw-hr. This power requirement will be practically the same for all missions. However, if the Agena deployment for some reason is delayed up to the maximum orbit staytime of 7 days, the power requirement could increase to about 65 kw-hr.

4.6 ENVIRONMENTAL CONTROL INTERFACE

The Agena is normally loaded with propellant at a temperature of 60°F. During prelaunch operation the Agena is further cooled, so that the propellant at liftoff is at a temperature on the order of 50 to 55°F. The reason for this is to optimize the performance capability, since more propellant can be loaded at a lower temperature. Actually, the propellant specific impulse will increase at a rate of 0.6 sec for 15 degrees temperature increase, but at the same time the propellant loading will decrease 164 pounds for the same temperature range, due to lower density. The net effect is a loss of performance on the order of 50 to 100 pounds of payload, depending upon the mission characteristic velocity.

Since the actual performance requirements are undefined at present, and since it will be difficult to maintain and control the Agena environment at a low temperature from installation in the cargo bay and until launch (up to 15 days), it was decided to accept the loss in performance resulting from higher temperature rather than to impose the requirement of a low temperature controlled within narrow limits. The recommended interface requirement is to maintain the cargo bay ambient temperature below 75°F during prelaunch operation when the Agena is installed.

Thermodynamic analysis has shown that the propellant temperature increase during ascent and orbital operations is practically negligible.

4.7 AGENA TUG SUPPORT EQUIPMENT

Table 4-3 presents a preliminary list of the Agena support equipment, including all nondeployable items chargeable to the Agena system; the development status has been indicated where possible. A corresponding weight estimate for the support equipment is given in Table 4-4. The support structure weight was estimated for a payload weight of 7,600 pounds (Viking mission) for the cantilevered configuration and 37,000 pounds (40,000 less Agena and support) for the extended cradle configuration.

The extendible boom deployment mechanism is not included in Table 4-4. If this system is used the Agena support equipment weight will be increased by 300 pounds.

4.8 ORBITER DESIGN REQUIREMENTS FOR AGENA INTEGRATION

The design requirements imposed upon the orbiter design as a result of incorporating the Agena vehicle system as an expendable upper stage to the space transportation system are summarized as follows:

a. Provide for and incorporate two propellant dump lines from the Agena service panel to the orbiter exterior skin line at an acceptable exit point.

b. Include provision for a small longitudinal acceleration (0.01g) during propellant dumping for propellant orientation.

c. Provide electrical power (approximately 20 kw-hr) and appropriate cabling to a plug-point in the cargo bay. This point should be as close as possible to the location of the Agena service panel.

d. Maintain cargo bay temperature below 75^{o}F from Agena installation until launch.

e. Provide access to the orbiter computer via the data bus for safety monitoring and prelaunch checkout functions.

f. Provide the required hardware and software for computer output in an Agena compatible format for Agena guidance update prior to deployment (state vector only).

g. Provide windows in the cargo bay doors for optical azimuth determination and correction, if required by mission.

h. Provide structural hard points in the cargo bay for Agena/payload attachment forces. These hard points should be located to permit the Agena to be installed in more than one longitudinal location.

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Table 4-3

EQUIPMENT LIST – AGENA SUPPORT SYSTEM

ITEM	TYPE OF SUPPORT			STATUS	QUANTITY	REMARKS
	Cantilevered	Extended	Cantilevered Adapter			
1. Payload Cradle				New	1	See tubing requirements under type of cradle.
3-1/2 OD x 0.120 Tubing	11 LFT					
3-1/2 OD x 0.083 Tubing	2 LFT					
3-1/2 OD x 0.049 Tubing	466 LFT		452 LFT			
3-1/2 OD x 0.065 Tubing	8 LFT	173 LFT				
3-1/2 OD x 0.200 Tubing		28 LFT				
3-1/2 OD x 0.250 Tubing		53 LFT				
3-1/2 OD x 0.220 Tubing		52 LFT				
3-1/2 OD x 0.350 Tubing		51 LFT				
2. Fitting Assembly–Agena to Support Cradle	X	X	X	New	4	
3. Fitting Assembly–Support Cradle to Orbiter-Cargo Bay	X	X	X	New	5	Cantilevered and Extended
					4	Cantilevered with Adapter
4. Deployment Mechanism Spar Boom Assembly and Synch/Control Installation	X	X	X	New	4	This deployment design is shown on the extended type cradle, but can be used on all three cradle concepts.
5. Propellant Dump	X	X	X	Qualified	1	Fuel
Propellant Dump Fittings–Agena Side					1	Oxidizer
Propellant Dump Fittings– Cradle				Redesigned	1	Fuel
Retraction Mechanism				Redesigned	1	Oxidizer
Propellant Dump Lines				New	1	Fuel
					1	Oxidizer
6. Electrical Interface	X	X	X			
MEI Disconnect–Agena				Qualified	1	
MEI Retractor System				New	1	
MEI Umbilical Cable				New	1	

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Table 4-3 (cont)

ITEM	TYPE OF SUPPORT			STATUS	QUANTITY	REMARKS
	Cantilevered	Extended	Cantilevered Adapter			
7. Safety Instrumentation	X	X	X			
Oxidizer Leak Sensor					2	
Fuel Leak Sensor					2	
Agena Tiedown Sensors					4	
Dumpline Disconnect Sensors					2	
MEI Disconnect Sensors					1	
Deployment Rate Sensors					4	
Cargo Bay Temperature Sensors					1	
Cable					1	
8. Deployment and Tiedown Cables and Connector	X	X	X	New	1	
9. Agena Service Panel	X	X	X	New	1	
DC/DC Converter				New	1	
Instrument Control and Power Distribution Box				New	1	
Standard Interface Unit				New	1	
Electrical Connectors					5	
Propellant Dump Fittings					2	
10. Propellant Dump Lines—Service Panel to Exit	X	X	X	New	2	
Electrical Cables					1	
Power—Service Panel to Forward Bulkhead				New	1	
Data Bus—Service Panel to Forward Bulkhead				New	1	
TLM—Service Panel to Forward Bulkhead				New	1	

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Table 4-4

AGENA SUPPORT SYSTEM WEIGHT

	Cantilevered Support System	Extended Cradle Support System	Cantilevered Support With Payload Adapter
Agena/Payload Support Structure	508	1083	642
Agena Service Panel and Electrical Comp	75	75	75
Dump Lines Retraction Mechanisms	103	103	103
Dump Lines	6	6	56
J-100 Disconnect	56	56	56
J-100 Cables	15	15	15
Cables for Deployment Control and Instrumentation	7	7	7
Propellant Dump Lines Within the Orbiter	11	11	11
Cables From Service Panel to Forward Bulkhead	15	15	15
TOTAL	796	1371	930

4.9 AGENA/PAYLOAD INTERFACE

The interface requirements between the Agena and its payload cannot be defined until payload specifications are available. The Agena has previously flown both separable spacecrafts and integrated payloads.

In the first case the spacecraft is a completely self-contained unit, requiring an interface that consists of support and attachment structure, separation mechanism, hard lines for on/off control, and power supply. Generally, the electrical connectors go through the Agena J-100 and to the spacecraft via another disconnect in order to simplify the umbilical wiring. The Agena J-100 will have approximately 35 vacant pins that can be used for spacecraft functions.

In the case of an integrated payload, the design requirements will depend upon the type of payload and its operational characteristics. In this case the Agena subsystems such as telemetry, attitude control, and maneuvering system will be used in support of the actual payload mission. The design for this type of mission must be investigated separately after each payload has been defined.

Section 5
EVOLUTIONARY AGENA TUG

Section 5
EVOLUTIONARY AGENA TUG

As specified in the statement of work for the Agena tug analysis, a small portion of the total effort was devoted to an investigation how the Agena vehicle concept could be best improved to utilize its capability for the space shuttle application. The basic design groundrules were the same as for the Agena tug design:

- Expendable Stage Only
- Use of Storable Propellants Only
- Maximum Use of Current, Existing Agena Characteristics
- Minimum Effect on Established Agena Space Tug/Shuttle Interface
- Selective Application of Long-Range Engine Improvements
- Design Constraints
  - 15 ft x 60 ft cargo bay
  - 65,000 lb maximum shuttle payload capability
  - 40,000 lb maximum shuttle landing capability

5.1 BASIC DESIGN PHILOSOPHY

Since the study guidelines specified maximum use of Agena characteristics, it was assumed that the Agena equipment discussed in Section 3 will also be sufficient to perform the missions of the evolutionary Agena tug. Some of the equipment will probably be improved during the period until the evolutionary Agena tug becomes a reality; however, this consideration was not included in the present analysis. The most significant improvements are expected to take place within the electronic area; new computers that will operate at a lower power level and be smaller in size and weight are expected to become available within the next few years.

The basic consideration for the evolutionary Agena tug is therefore to improve the payload weight capability and to optimize the Agena configuration within the design constraints for this specific application. An artist's conception of the evolutionary Agena tug configuration is shown in Fig. 5-1.

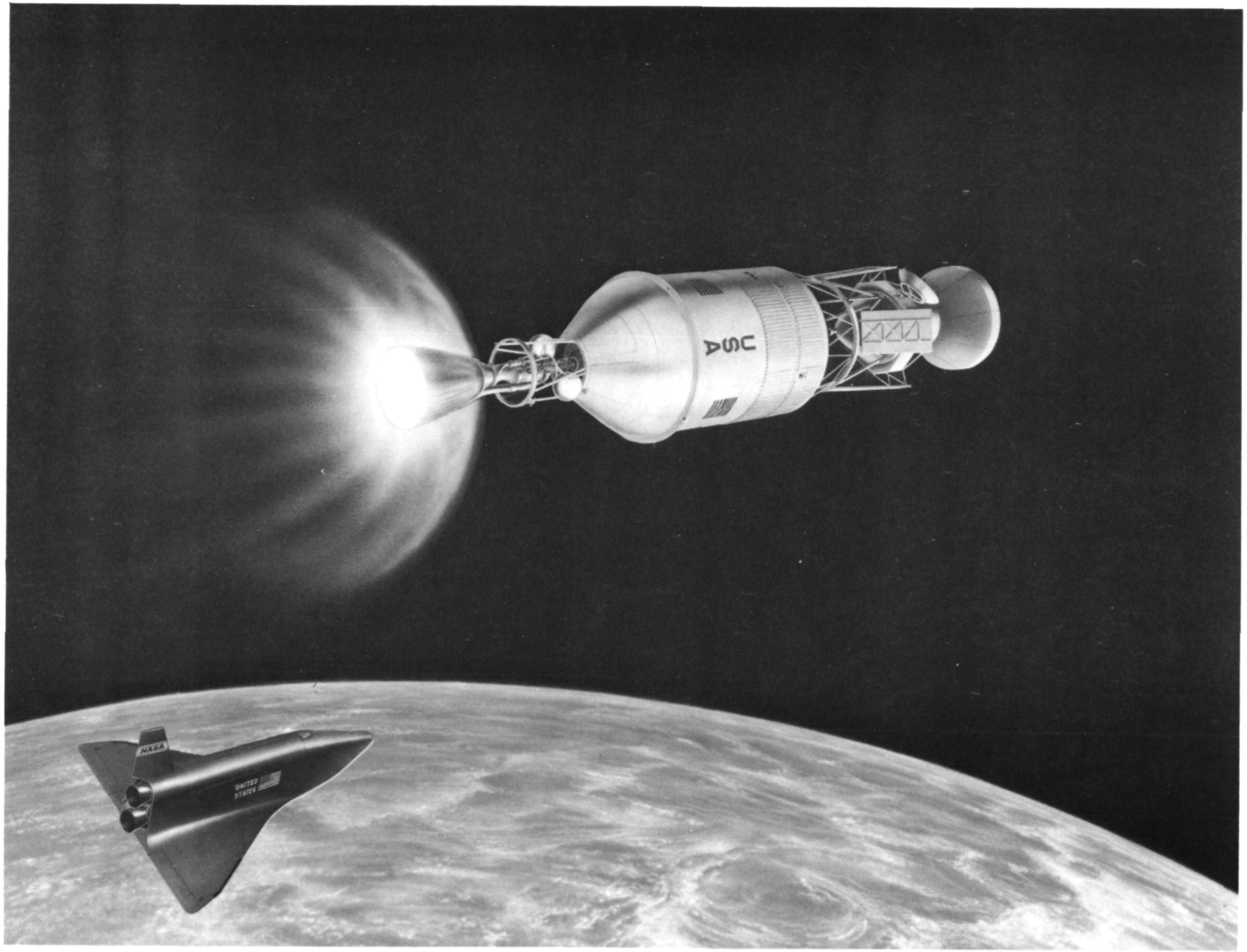


Fig. 5-1 Artist's Conception of Evolutionary Tug Configuration With Mars-Viking Payload

If the shuttle capability were not limited, the Agena performance capability would increase with increased propellant loading. However, this limitation puts a severe restriction upon the Agena propellant loading. So a tradeoff analysis must be performed to determine the optimum balance between payload weight and propellant weight that will give the maximum overall performance. The optimum propellant weight will also be a function of the mission and the corresponding characteristic velocity that the Agena vehicle must deliver. An analysis of the presently available mission model for the first 10 years of shuttle operation shows a high concentration of missions at the synchronous equatorial orbit (V_{ch} = 14,100 ft/sec). To capture as many as possible of these missions, it is important to optimize the performance capability for this characteristic velocity; therefore, the synchronous equatorial mission was used as the design point for this analysis. This means that the evolutionary stage will be sized for maximum propellant loading at this characteristic velocity, and for missions of lower energy the propellants will be offloaded to give the best possible performance within the shuttle payload weight constraints of 65,000 pounds. This is indicated by Fig. 5-2, which shows how the resulting performance capability will be reduced for missions below a characteristic velocity of 14,100 ft/sec.

5.2 PROPULSION SYSTEM

An important parameter with respect to the performance capability is selection of a suitable propulsion system. The study guidelines specify that the propellants must be storable, and all the mission requirements as far as restart capability, number of burning periods, and mission duration are the same as for the Agena tug configuration. Lockheed has for some time investigated what propellant combination would be most suitable for an improved version of the Agena, and two basic propellant combinations have been selected as promising candidates:

- HDA/USO (UDMH plus Silicone Oil)
- N_2O_4/MMH + SO (MMH plus Silicone Oil)

Both of these combinations are compatible with the Agena system and can be used in the Agena engine with a minimum of modifications. The propulsion data pertinent to this study are summarized in Table 5-1. To ensure proper hot restart for a short cooldown between engine burning periods the tank working pressure specified in

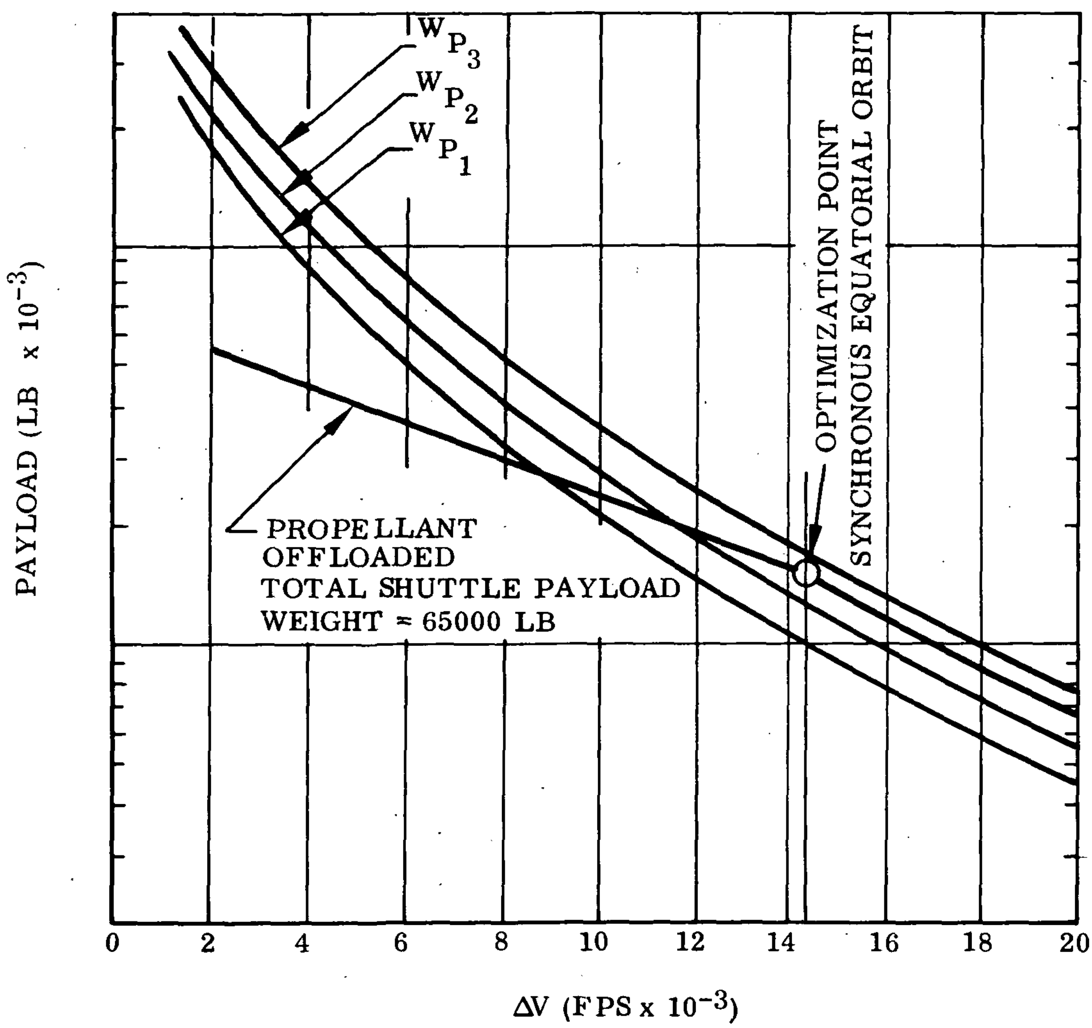


Fig. 5-2 Evolutionary Agena Tug Design Philosophy

Table 5-1

PROPULSION DATA FOR HDA/USO AND N_2O_4/MMH PROPELLANT COMBINATIONS

The following propulsion data are based upon 50,000 pounds of total propellants at 75°F:

Densities

Specific Gravity of HDA/USO ___ 1.6272 (101.48 lb/ft^3)/0.7864 (49.045 lb/ft^3)
Specific Gravity of N_2O_4/MMH ___ 1.436 (89.559 lb/ft^3)/0.8755 (54.602 lb/ft^3)

Vapor Pressures

HDA/USO ___ 13.0 psia/2.9 psia
N_2O_4/MMH ___ 17.0 psia/0.90 psia

Ullage Volume

5.0 ft^3 in All Tanks

Nonimpulse Propellants (Ten starts)

HDA/USO ___ 667.2 lb/146.6 lb
N_2O_4/MMH ___ 608.0 lb/153.1 lb

Engine Overall Mixture Ratio

HDA/USO ___ 2.653:1
N_2O_4/MMH ___ 1.82:1

Engine I_{sp}

HDA/USO ___ 310 sec
N_2O_4/MMH ___ 322 sec

Engine Flow Rate

HDA/USO ___ 56.84 lb/sec
N_2O_4/MMH ___ 50.60 lb/sec

Engine Thrust

HDA/USO ___ 17620
N_2O_4/MMH ___ 16300

Table 5-2 should be maintained. The difference in tank pressures result from variations in vapor pressure between the propellant components.

Table 5-2
SPACE TUG MAXIMUM WORKING DESIGN TANK PRESSURES (PSIA)

	HDA/USO	N_2O_4/MMH + SO
Anodized Pumps	48/28	94/22
Anodized Pumps and Stainless Steel Bearing Support (Oxidizer Pump)	33/43	74/25
Anodized Pumps, Stainless Steel Bearing Support (Oxidizer Pump), and Quench	30/25	52/22

The recommended design solution for accomplishing hot-pump restart, using the HDA/USO or N_2O_4/MMH propellant combinations is to anodize both pumps; or both pumps may be anodized in combination with a stainless-steel oxidizer bearing support. Both solutions are passive and do not detract from propulsion system reliability.

In designing tanks for the space tug, maximum tank working pressure has a direct and significant effect on tank weight. Therefore, in addition to the anodized pumps and stainless steel oxidizer pump bearing support, the use of a quench system for pump assembly cooling is introduced for consideration. This quench system would utilize the engine oxidizer propellant that is normally vented overboard following each burn and route it through the hot turbine manifold and rotor. The system could introduce additional valving and sequencing into the present Agena propulsion system design with an attendant increase in complexity. Therefore, until more detailed space tug design tradeoffs are made, a passive solution is recommended. However, if significant tank weight savings are required, a quench or other system could be considered for development, and those lower pressure values presented in Table 5-2 used for preliminary estimates.

5.3 TANK DESIGN

5.3.1 Location of HDA Tankage

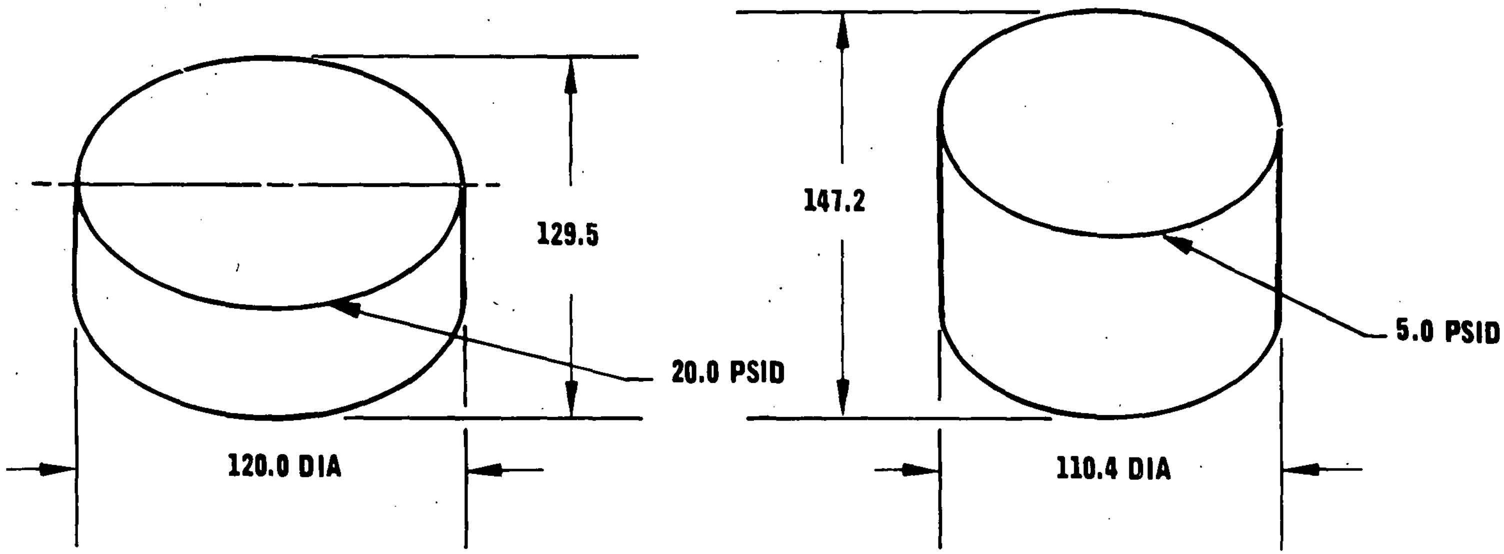
Before a point design of the evolutionary stage Agena for a given propellant loading was undertaken, several elements were investigated that contribute significantly to the weight and geometry of the stage. The first investigation involved the optimum location of the oxidizer (HDA) tankage. Since a common bulkhead separates the forward and aft tanks, it is necessary to maintain a constant pressure in the forward tank to prevent buckling and possible collapse of the tank membrane. Placing the HDA tank forward produces an automatic positive pressure of 20.0 psid across the membrane due to the higher operating pressure of the HDA tankage. Additionally, the higher vapor pressure of the HDA tank requires less helium to expel the liquid.

Utilization of a true ellipsoid (no cylindrical section) does not constrain the diameter of the tanks, but allows the diameter to be determined by the tankage requiring the greatest volume in the forward tank, which is the oxidizer. This philosophy also yields the shortest overall tankage length.

Placing the HDA in the aft tank automatically dictates that the pressure of the UDMH in the forward tank be 5.0 psid higher than the 48.0 psia in the HDA tankage. Since the operating pressure is higher in both tanks with this arrangement, a severe weight penalty to both tanks results. In consideration of the inherent benefits, the placement of the HDA tankage forward was selected. Figure 5-3 illustrates these two concepts and their effect upon the tank geometry.

5.3.2 Tankage Configuration

A second investigation determined the effects on the tank weights and lengths as a function of tankage diameters for a given propellant loading. Total propellant loadings of 35,000 pounds, 48,000 pounds, and 56,000 pounds were considered for each of the tankage configurations, which provided sufficiently accurate scaling laws for evaluating the generated data. Both the oxidizer and fuel tanks were sized to include an ullage capacity of 5 cubic feet at a temperature of 75°. An O/F ratio of 2.65:1 was used



HDA

13.0 PSIA VAPOR PRESS
35.0 PSIA HELIUM
48.0 PSIA OPERATING

UDMH

2.9 PSIA VAPOR PRESS
25.1 PSIA HELIUM
28.0 PSIA OPERATING

GUIDELINES

- 51,300 POUNDS STORAGE CAPACITY
- NO CYLINDRICAL SECTION IN FORWARD TANK
- VAPOR PRESSURES:
  HDA 13.0 PSIA,
  UDMH 2.9 PSIA
- $\frac{a}{b} = \sqrt{2:1}$ ELLIPSOIDAL FORWARD TANK

UDMH

2.9 PSIA VAPOR PRESS
50.1 PSIA HELIUM
53.0 PSIA OPERATING

HDA

13.0 PSIA VAPOR PRESS
35.0 PSIA HELIUM
48.0 PSIA OPERATING

Fig. 5-3 Location of HDA Tankage

for sizing the oxidizer and fuel tanks. It was determined that for each family of configurations for a given propellant loading that the 90-inch diameter tank was the lightest, followed by the 105-inch diameter, with the variable diameter exhibiting the heaviest weight. The weight differential between tanks within a family was less as the propellant loading diminished. However, the total weight differential is on the order of 12 to 20 percent of the tank weight. These tank configurations are shown in Fig. 5-4.

As a representative example of the results for a propellant loading of 48,000 pounds it was determined that the 90-inch-diameter tank weighed 436.0 pounds, the 105.0-inch-diameter tank weighed 458 pounds and the 118.0-inch-diameter tank weighed 514 pounds.

The third study involved evaluation of the stage length for each tank configuration as a function of propellant loading. The stage lengths were derived by adding the constant lengths for the forward and aft sections to the variable lengths of each tank configuration. The relationship in lengths between the three tank configurations is expressed in Fig. 5-5. As expected, the stage utilizing the variable tank diameter geometry produces the shortest stage length.

5.3.3 Optimum Propellant Loading and Tank Size

As discussed under par. 5.1, the evolutionary Agena tug will be designed to give maximum payload capability at a velocity corresponding to injection into a synchronous equatorial orbit. Assuming that the maximum shuttle capability of 65,000 pounds can be used, the following weight relationship must be satisfied:

> (Agena empty weight + Agena propellant weight + payload weight + support equipment weight) = 65,000 pounds.
>
> The support weight is practically constant for all missions, 800 pounds.
>
> The maximum Agena ignition weight, including the payload is then 65,000 - 800 = 64,200 pounds.

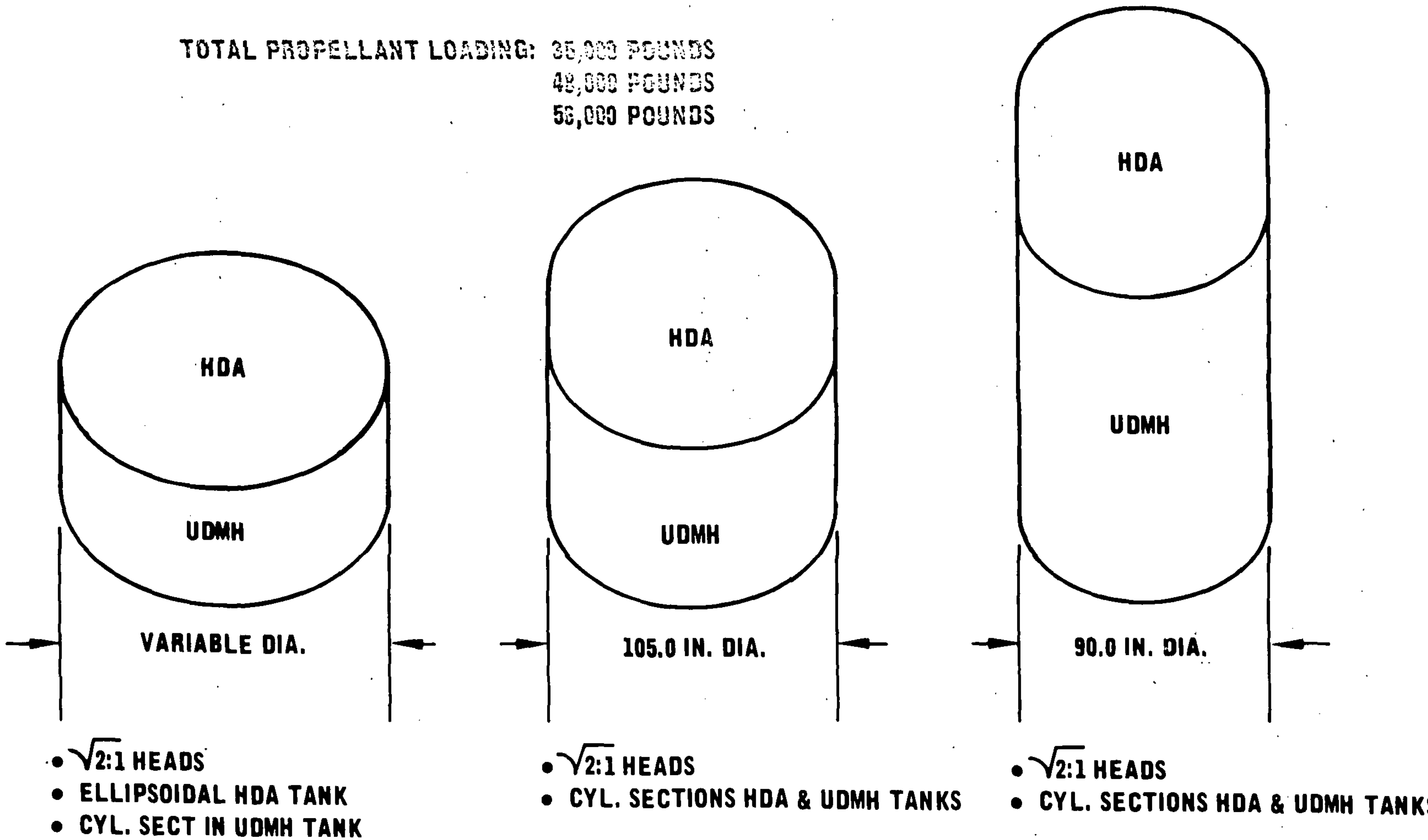


Fig. 5-4 Tankage Configurations

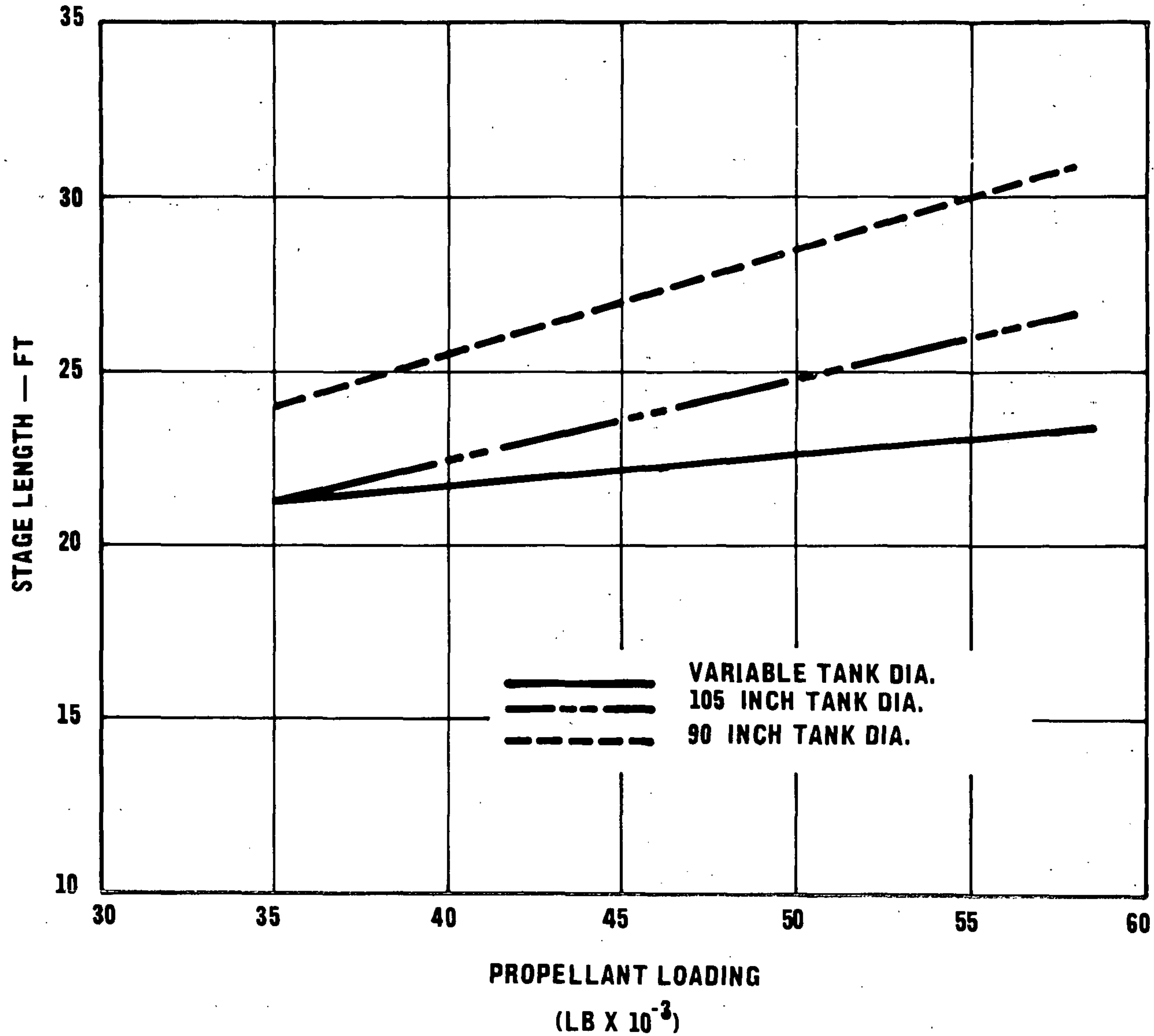


Fig. 5-5 Stage Length Versus Propellant Loading

Figure 5-6 shows the variation of payload weight vs propellant weight for the velocity corresponding to the synchronous equatorial mission. Introducing the constraint on the vehicle ignition weight gives an optimum propellant loading of 48,800 pounds. Figure 5-7 gives the relationship between the tank propellant capacity, tank diameter, and length. This curve is based on a $\sqrt{2}$ ellipse ratio to control the tank endcap geometry, which corresponds to the variable tank diameter configuration previously discussed. The tank dimensions corresponding to a total propellant load of 48,800 pounds are:

- Diameter 118.8 inches
- Length 126.0 inches

A direct comparison of a 90-inch-, 105-inch-, and 118.8-inch-diameter tankage for a propellant loading of 48,800 pounds is illustrated in Figure 5-8. Even though the tankage configuration for the 90-inch-diameter yielded the lightest weight, the stage employing the variable tank diameter is 5 feet shorter. Although weight of the tankage is an important element to be considered, it was concluded that higher overall benefits could be achieved by shortening the Agena stage length to provide the maximum payload length within the shuttle cargo compartment. For this reason, the variable diameter configuration was selected for further consideration of the evolutionary Agena space tug.

5.4 HDA ULLAGE PRESSURE CONSIDERATIONS

As mentioned, the variable diameter tankage configuration having a diameter of 118.8 in. contains 48,800 pounds of propellant, which is optimized for the synchronous equatorial mission. The ullage volume of 5 cubic feet for these tanks was established for a maximum propellant bulk temperature of 75°F. Increasing tankage size to 120 inches in diameter for a propellant loading of 48,800 pounds provides an ullage volume of 6.5 percent in the tankage, which allows a significant rise in bulk temperature and corresponding ullage pressure without approaching the design ultimate strength of the tank membrane. As shown in the ullage pressure vs temperature plot for the HDA tank (Fig. 5-9) the temperature could rise to 100°F and maintain a comfortable structural margin of safety in the HDA tankage. Significant improvements are achieved in the UDMH tank; however, the study was made for the HDA tank only, since the higher

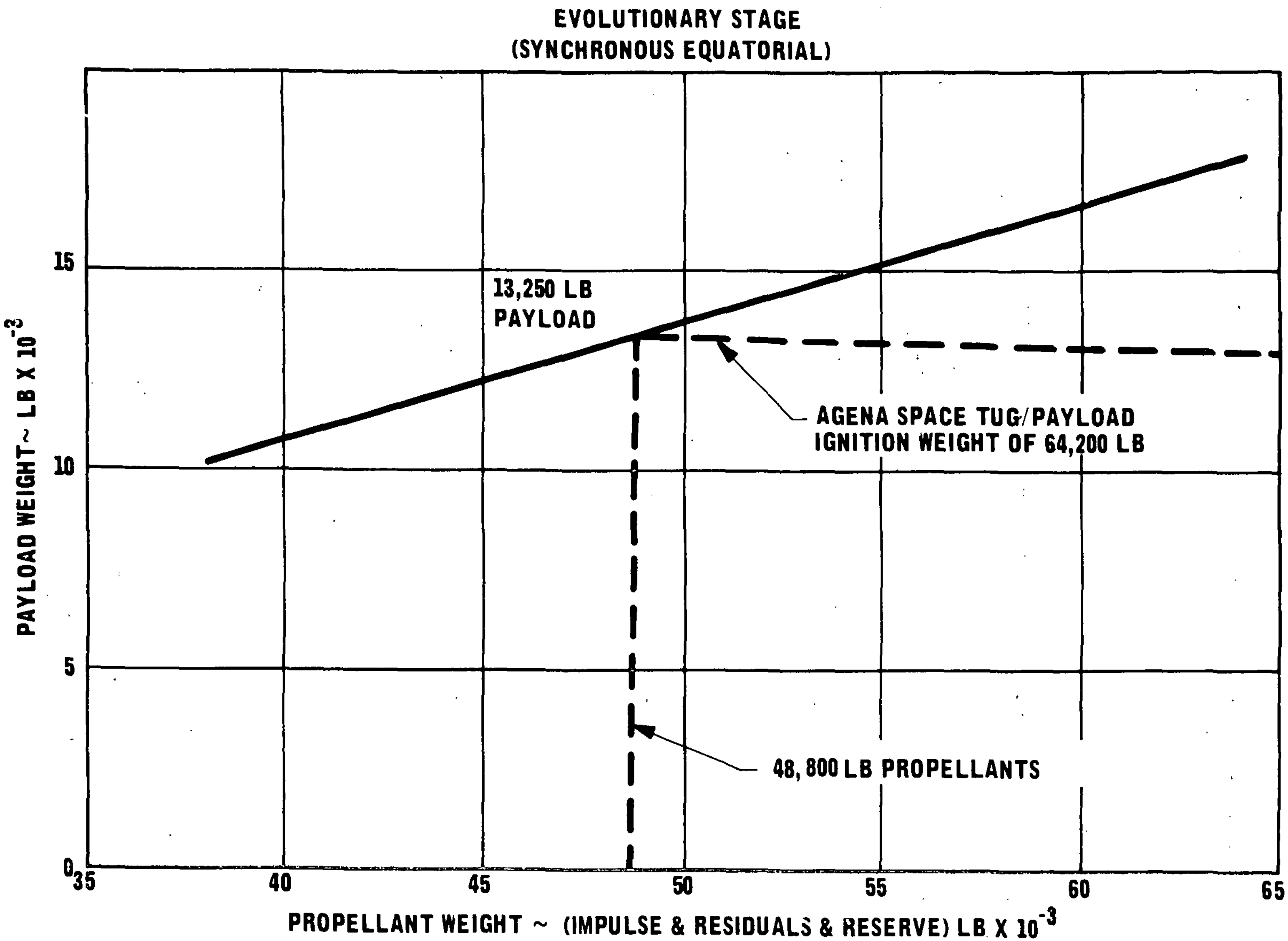


Fig. 5-6 Optimum Propellant Load

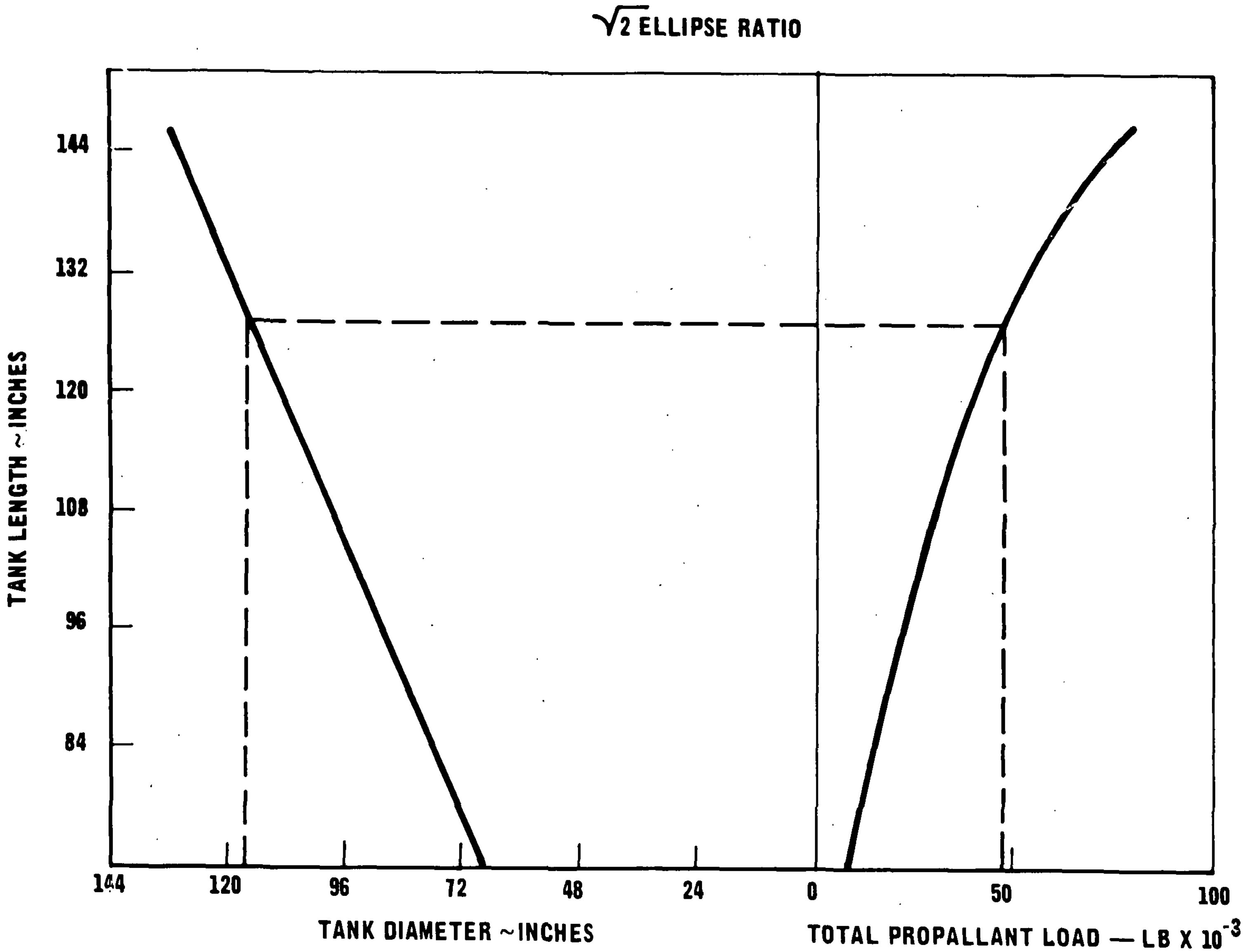


Fig. 5-7 Evolutionary Stage Propellant Tank Sizing

PROPELLANT WEIGHT = 48,800 LB

HDA/UDMH

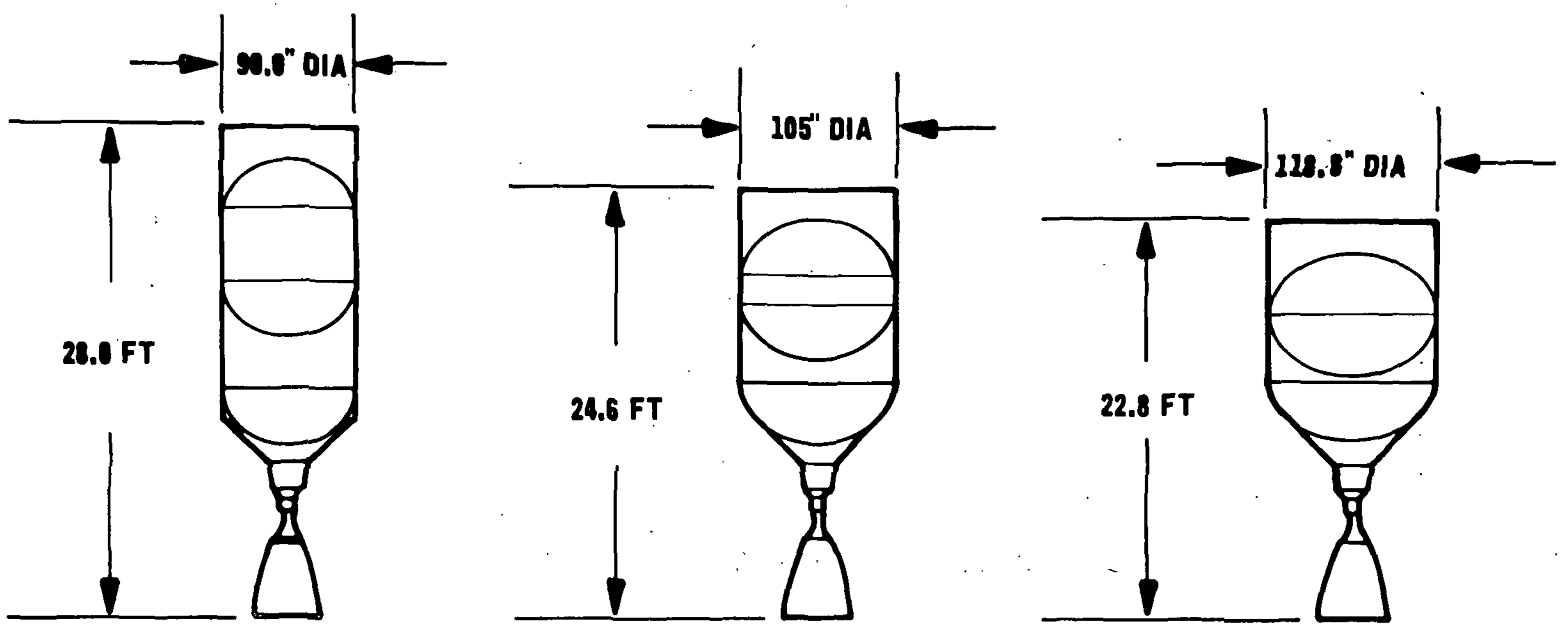


Fig. 5-8 Evolutionary Stage Sizing

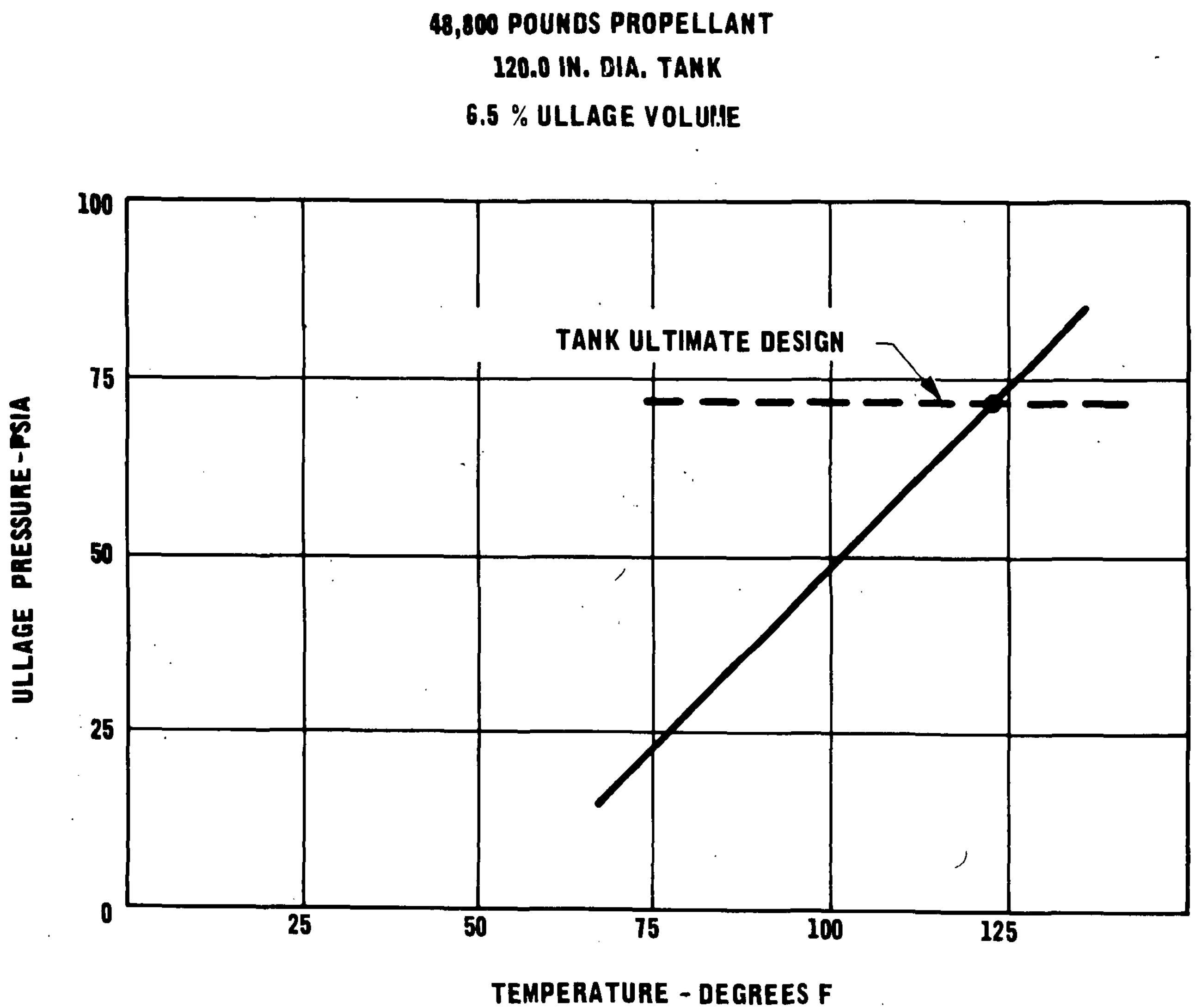


Fig. 5-9 HDA Ullage Pressure Versus Temperature

vapor pressure of the oxidizer makes the temperature rise more acute for this tank. If the temperature within the loaded tank does not exceed 75°F to drive the ullage pressure up and 5 cubic feet are provided for the ullage area, a maximum of 51,300 pounds of propellant can be stored in the 120-inch-diameter tankage. In view of the significant gains associated with this concept, the 120-inch-diameter tank was selected for the point design of the evolutionary stage Agena.

5.5 EVOLUTIONARY STAGE CONFIGURATION

After the propellant tank configuration was established and the exact propellant loading was selected, a point detail design for the evolutionary Agena space tug with a diameter of 120 inches and a length of 275 inches was completed. The inboard profile (Fig. 5-10) shows the major subsystems and principal components. Basically, the evolutionary Agena space tug is comprised of three major sections, the forward equipment section, the intermediate propellant tank section, and the aft propulsion section. It strongly resembles the present Agena vehicle.

All of the guidance, electronics, power propellant tank pressurization, and telemetry systems are installed in the forward section. The structure for this section is semi-monocoque, utilizing external trapezoidal stringers and internal beams that provide structural stiffness as well as mounting bases for the functional equipment installed in this section. The forward oxidizer tank is a true $\sqrt{2:1}$ ellipse; the lower head provides a common bulkhead for both tanks. The aft head of the fuel tank is $\sqrt{2:1}$ semi-ellipse. A cylindrical section joins the two tanks at a Y-ring near the equator of the oxidizer tank. The membrane, as well as other tank components, will be made of 2021 aluminum alloy.

The aft propulsion section is comprised of an engine thrust cone attached to the fuel tank head, the rocket engine accessories, and supporting truss. The attitude control thrusters and nitrogen storage tanks are also mounted in the aft section.

An artist's drawing of this configuration is shown in Fig. 5-11.

5.5.1 Structural Capability – Cantilevered Support

Although a lighter weight space tug that would provide supports at both the payload/Agena interface and at the payload CG could be conceived, a cantilevered support concept was chosen to maximize payload flexibility and simplicity, as well as to reduce payload support equipment weight. Since the shuttle abort mode landing condition with the payload attached to the dry Agena imposed the most severe loads, the Agena structure was designed to this mode. The larger, 120-inch-diameter stage increases the strength capability of the evolutionary stage. Figure 5-12 shows the space tug installed inside the shuttle payload compartment in the most aft position for maximum utility of the cargo compartment when transporting long, low-density payloads. The structural load capability of the evolutionary Agena space tug is expressed in terms of the payload lever arm and the payload weight for a corresponding CG location. The CG locations for the Viking and Intelsat IV payloads are shown for reference.

5.5.2 Interface Comparison

The evolutionary stage impact on the established space shuttle/Agena space tug interface is minimal. The cargo bay support cradle structure requires redesign to accommodate the larger stage diameter. The weight tradeoff between the reduction in size of the support structure relative to the required increase in tube size and gage results in a nominal support structure weight decrease of 30 pounds. Large-diameter emergency dump lines may be required to compensate for the increased propellant load if the dump time is considered to be excessive. The interface characteristics are summarized in Table 5-3.

Since the evolutionary stage utilizes the same electronics as the Agena space tug, no changes are required in the Agena/payload service panel or the Agena console located in the orbiter mission specialist station. Safety instrumentation, propellant tanking techniques, and vehicle flight operations also remain the same.

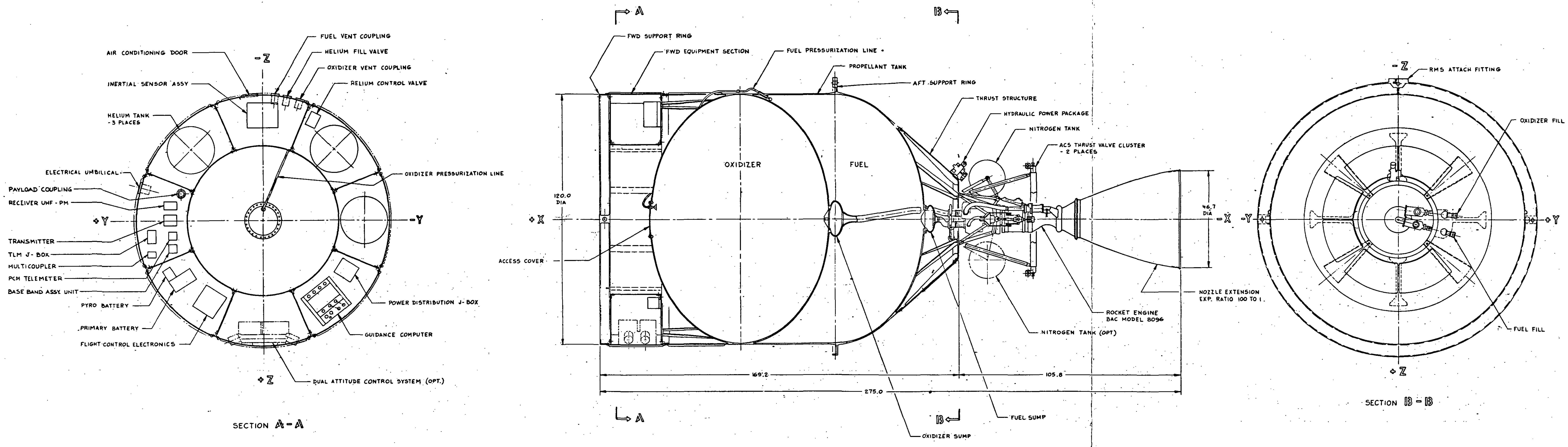


Fig. 5-10 Evolutionary Agena Space Tug Inboard Profile

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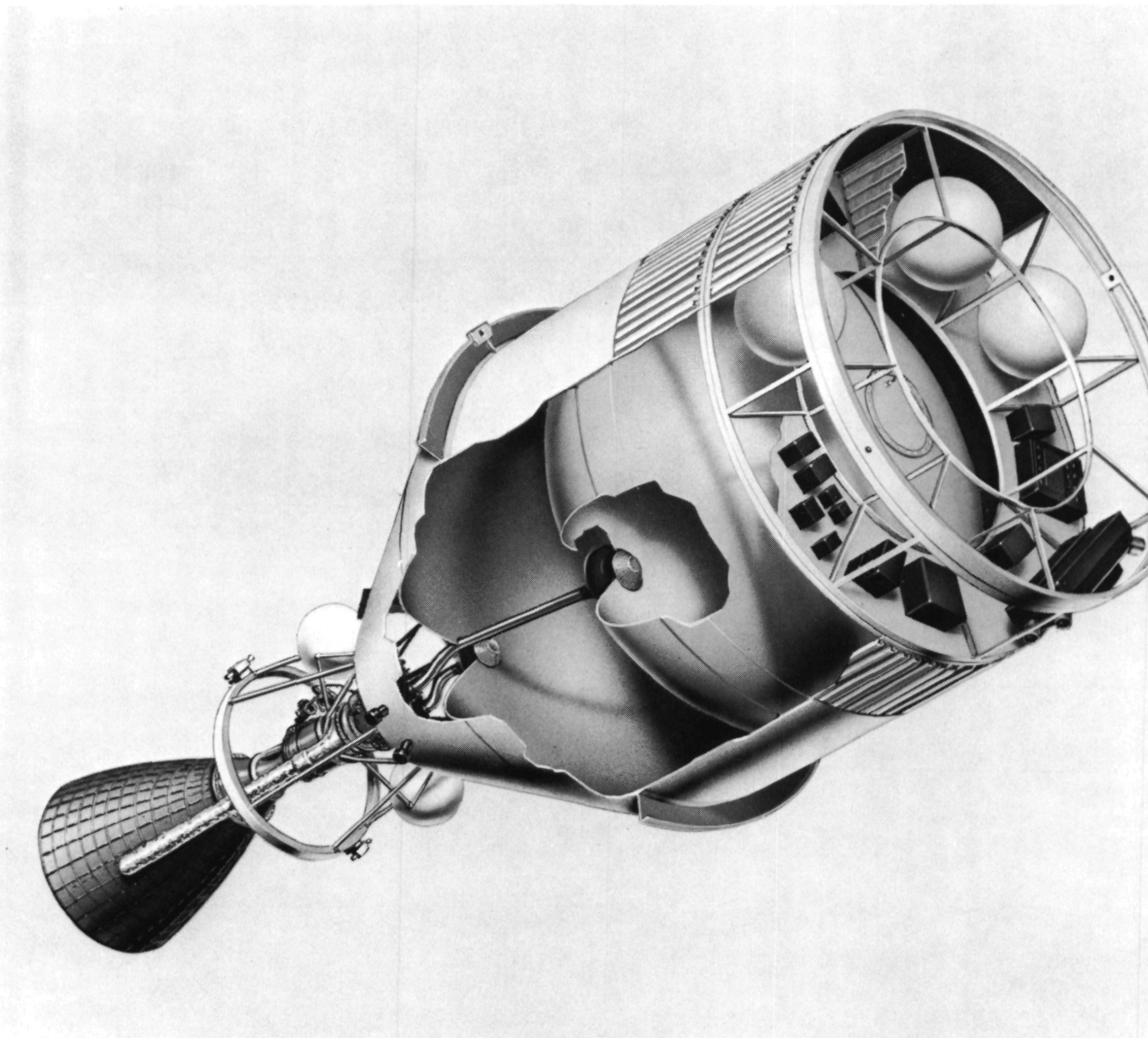


Fig. 5-11 Evolutionary Agena Space Tug

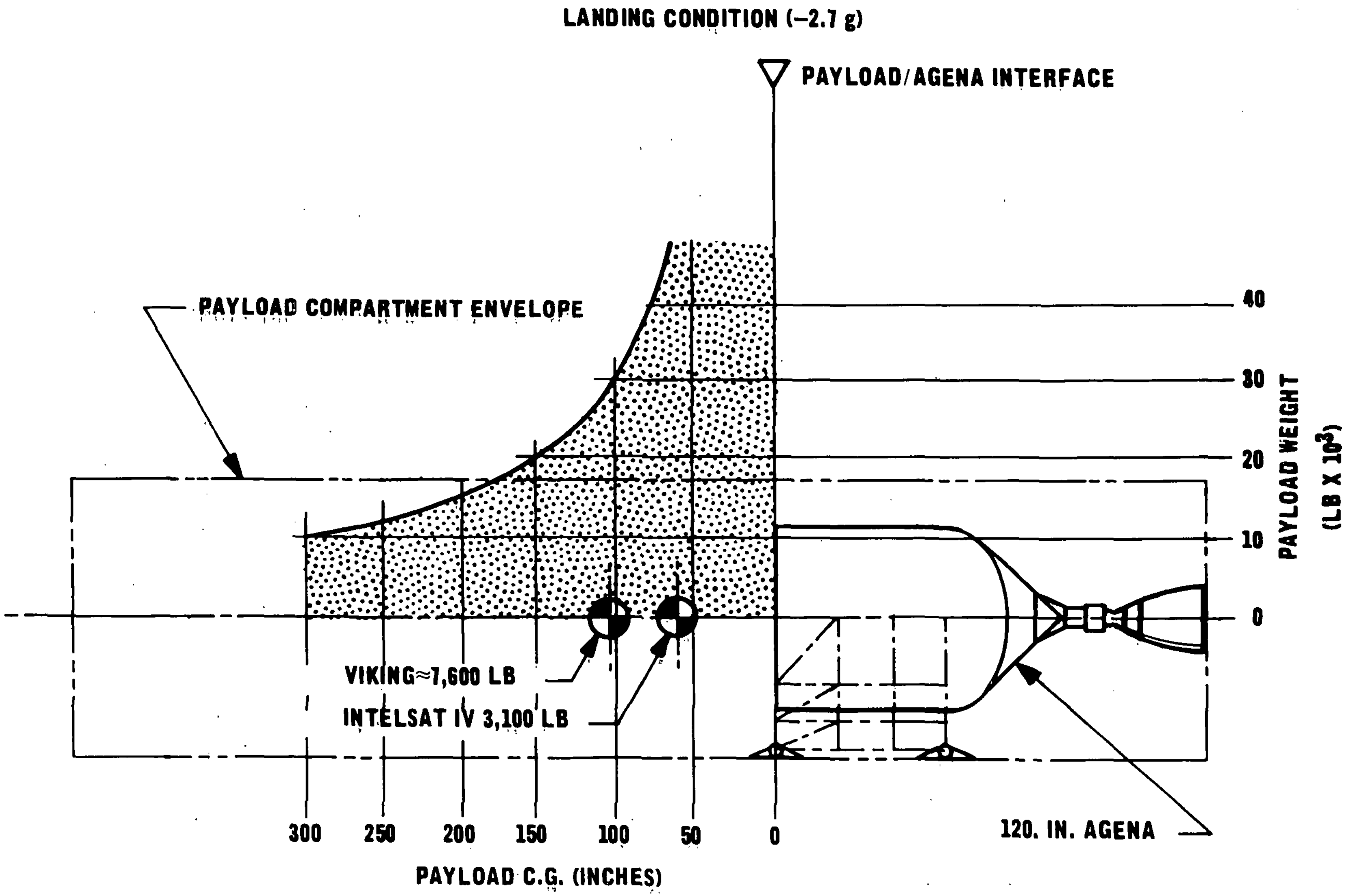


Fig. 5-12 Structural Capability – Cantilevered Support

Table 5-3

SUMMARY OF INTERFACE CHARACTERISTICS

Interface Area	Evolutionary Stage Comparison With Agena Space Tug
Cargo Bay Support Structure	Modified for 10-ft Vehicle Diameter
Emergency Dump	Same (Larger Diameter Lines May be Required)
Electrical Umbilical	Same
Disconnects	Same
Agena/Payload Service Panel	Same
Safety Instrumentation	Same
Agena Specialist Console	Same
Propellant Tanking and Vehicle Handling	Same
Vehicle Operations	Same

5.5.3 Weight Summary

Table 5-4 gives a weight breakdown of the evolutionary Agena tug designed for UDMH/HDA propellants according to subsystem; all the subsystem components are the same as those used for the Agena tug configuration discussed under par. 2.3. The only difference in weight between the two configurations is therefore in the structural subsystem. Also, for the evolutionary Agena a general contingency of 10 percent has been added to all subsystems to cover uncertainty of new designs and added weights of increased wire lengths, etc. Table 5-4 also shows the difference in configuration weight between the three model missions used for this analysis. Again the rationale behind the seleetion of the mission peculiar equipment and the configuration definition is the same as for the Agena tug configuration discussed in Section 3.

Table 5-4

WEIGHT BREAKDOWN FOR EVOLUTIONARY AGENA TUG USING UDMH/HDA

	Planetary Injection	Synchronous Equatorial Injection	30-day Low Earth Orbit Mission
Structure			
Forward Section	211	211	211
Tank Section	478	478	478
Aft Section			
Thrust Cone	58	58	58
Aft Skirt and Ring	121	121	121
Structure for N_2 Bottles and Thrusters	7	7	7
Total Structures	875	875	875
Electrical Power			
Primary Batteries	32.2	120.0	52.0
Power Distribution J-Box	9.1	9.1	9.1
Aft Control and Instrument. J-Box	6.2	6.2	6.2
Main Power Transfer Switch	2.6	2.6	2.6
Wire Harnesses	37.4	37.4	37.4
Pyrotechnic Control Box	4.5	4.5	4.5
Solar Array	—	—	20.0
Charge Control	—	—	18.0
Cables	—	—	10.0
Total Electrical Power	92.0	180.0	160.0
Propulsion			
Rocket Engine	225.2	225.2	225.2
Nozzle Extension Kit (46 + 27)	73.0	73.0	73.0
Multistart Kit	28.0	28.0	28.0
Propellant Fuel and Oxidizer Feed Bellows	2.0	2.0	2.0

Table 5-4 (Cont)

	Planetary Injection	Synchronous Equatorial Injection	30-day Low Earth Orbit Mission
Propulsion (Cont)			
Helium Fill Couplings	0.3	0.3	0.3
Pyro He Control Valve	3.8	3.8	3.8
M-69 Pressure Squib	0.1	0.1	0.1
Propellant Dump Valves and Lines	2.8	2.8	2.8
Regulator Pressure System	7.9	7.9	7.9
Fast Shutdown Kit	1.9	1.9	1.9
Propellant Vent Coupling	0.4	0.4	0.4
Helium Tanks (3)	47.7	47.7	47.7
Check Valve	0.2	0.2	0.2
Fuel and Oxidizer Feed Bellows	2.7	2.7	2.7
Propellant Isolation Valves	11.0	11.0	11.0
Helium Plumbing	2.0	2.0	2.0
Propellant Plumbing	8.6	8.6	8.6
Engine Exhaust Shields	3.5	3.5	3.5
Total Propulsion	421.0	421.0	421.0
Communication			
PCM TLM, Type IV	4.0	4.0	4.0
TLM J-Box	5.2	5.2	5.2
Decoder	2.3	2.3	2.3
Multicoupler	1.6	1.6	1.6
Receiver-Demodulator	9.0	9.0	9.0
Transmitter	3.5	9.0	3.5
Baseband Unit	1.0	1.0	1.0
Coax Cables	2.0	2.0	2.0
Omni-Antenna	1.5	1.5	1.5
Parabolic Antenna	—	9.0	—
Total Communication	30.0	45.0	30.0

Table 5-4 (Cont)

	Planetary Injection	Synchronous Equatorial Injection	30-day Low Earth Orbit Mission
Guidance and Control			
Flight Control Electronics	8.6	8.6	—
Inertial Sensor Assembly	36.6	36.6	36.6
Guidance Computer	46.8	46.8	46.8
Hydraulic Power Package	8.7	8.7	8.7
Hydraulic Actuators (2)	6.7	6.7	6.7
Nitrogen Tank	21.2	21.2	21.2
Nitrogen Regulator	7.9	7.9	7.9
Nitrogen Fill Valve	0.3	0.3	0.3
Thrust Valve Cluster (2)	9.2	9.2	9.2
Attitude Control Plumbing	2.8	2.8	2.8
Nitrogen Temperature Probe	0.5	0.5	0.5
Nitrogen Tank Fittings	0.8	0.8	0.8
Hydraulic Plumbing	3.0	3.0	3.0
Status and Safety Checkout Sensors	10.0	10.0	10.0
DACS Mounting Hardware	—	—	26.5
Horizon Sensor Mixer Box (2)	—	—	22.0
Horizon Sensor Heads (4)	—	—	22.2
Gyro Reference Assembly	—	—	40.0
Orbit Electronics Assembly	—	—	17.2
Augmented Electronics Assembly	—	—	20.2
Cable Assembly, Flat	—	—	5.5
Nitrogen Regulator	—	—	9.2
Wire Harness	—	—	2.5
Nitrogen Bottle, Spherical (1)	—	—	22.5
Plumbing	—	—	21.8
Total Guidance and Control	163.0	163.0	364.0

Table 5-4 (Cont)

	Planetary Injection	Synchronous Equatorial Injection	30-day Low Earth Orbit Mission
Contingency	160.0	170.0	180.0
Total Configuration Dry Weight	1741.0	1854.0	2030.0
Helium Gas	10.0	10.0	10.0
Nitrogen Gas	31.0	31.0	81.0
Propellant Loaded (UDMH/HDA) ($75^{o}F$)	45,610	48,792	17,230
Total Configuration Wet Weight	47,392	50,687	19,351

The propellant loading for the synchronous-equatorial orbit mission is 48,800 pounds. For the planetary injection mission the velocity requirement is less than that of the synchronous equatorial mission; therefore, the propellant loading must be reduced somewhat, so that the total weight of the shuttle payload does not exceed the 65,000 pounds. The optimum propellant loading for this case was found to be 45,600 pounds. For the sun synchronous low altitude orbit mission, the shuttle must be launched into a near polar orbit. The total shuttle payload capability for this launch is only 40,000 pounds. The Agena tug must therefore be offloaded with respect to propellant, so that this weight is not exceeded. The optimum propellant load for this mission was the determined 17,230 pounds. This will reduce the performance capability of the evolutionary Agena tug considerably for this mission; as discussed in Section 6, the Agena space tug (60-inch diameter) will actually show a higher performance capability.

Table 5-5 gives a similar weight breakdown for an evolutionary Agena tug designed for N_2O_4/MMH propellants. The only difference between these configurations is in the tank weights, since these propellants require a higher tank pressure. The tank volume was the same for both vehicles, since an optimization of the tank configuration similar to that done for the UDMH/HDA propellant was not done. The difference, however, is expected to be insignificant.

Table 5-5

WEIGHT BREAKDOWN FOR EVOLUTIONARY AGENA TUG USING MMH/N_2O_4

	Planetary Injection	Synchronous Equatorial Injection	30-day Low Earth Orbit Mission
Structure			
Forward Section	211	211	211
Tank Section	577	577	577
Aft Section	186	186	186
Total Structure	974	974	974
Total Electrical Power	92	179.8	159.8
Total Propulsion	421.1	421.1	421.1
Total Communication	30.1	44.6	30.1
Total Guidance and Control	163.1	163.1	364.1
Contingency	170.0	180.0	190.0
Total Configuration Dry Weight	1850.0	1963.0	2139.0
Helium Gas	10	10	10
Nitrogen Gas	31	31	81
Propellant Loaded (MHH/N_2O_4) (75^oF)	44,767	47,948	16,751
Total Configuration Wet Weight	46,658	49,952	18,981

Finally, Table 5-6 gives weight sequences for the three model missions, from the total Agena weight and until the mission is completed. This table includes both the UDMH/HDA and the MMH/N_2O_4 versions of the evolutionary Agena configuration. The support equipment weight was obtained from Table 2-5, using a cradle compatible with the payload capability.* The nonimpulse propellant was estimated on the basis of the required number of burning periods for each mission.

An artist's conception of the evolutionary stage Agena is shown in Fig. 5-13.

*For the extended cradle support the weight was reduced by 40 pounds, since the structure mounts of the support cradle are shorter.

Table 5-6

WEIGHT SEQUENCE

	Planetary Injection		Synchronous Equatorial Injection		Low Earth Orbit 30-day Mission	
	UDMH/HDA	MMH/N_2O_4	UDMH/HDA	MMH/N_2O_4	UDMH/HDA	MMH/N_2O_4
Total Evolutionary Agena Tug Installed Weight (No Payload)	48,188	47,454	51,483	50,748	20,691	20,321
Less Agena Support Weight	796	796	796	796	1,340	1,340
Evolutionary Agena Deployment Weight	47,392	46,658	50,687	49,952	19,351	18,981
Less Impulse Propellant	45,148	44,299	48,196	47,358	16,504	16,052
Pre-Flows	11	11	33	30	66	66
Post-Flows	60	54	180	162	360	324
N_2-Gas Used	8	9	8	9	63	63
Evolutionary Agena Weight at Spacecraft Separation	2,165	2,303	2,270	2,393	2,358	2,476
Less Propellant Residuals	167	178	167	178	167	178
Propellant Margin	224	225	216	220	133	131
Remaining N_2-Gas	23	22	23	22	18	18
He-Gas	10	10	10	10	10	10
Evolutionary Agena Dry Weight	1,741	1,850	1,854	1,963	2,030	2,139

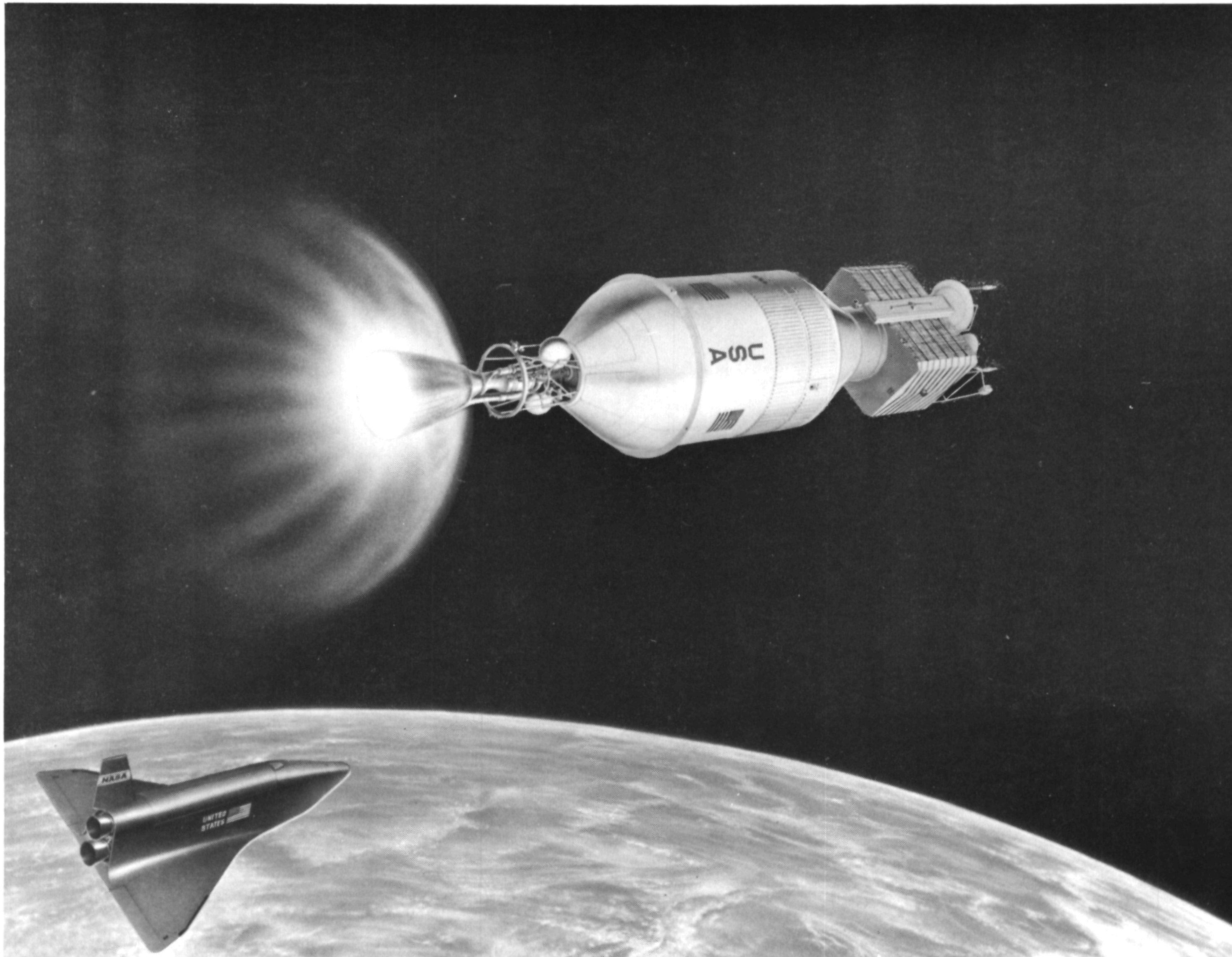


Fig. 5-13 Evolutionary Stage Agena With Intelsat IV Payload

Section 6
PERFORMANCE CAPABILITY

Section 6
PERFORMANCE CAPABILITY

6.1 PERFORMANCE GUIDELINES FOR BASELINE AGENA SPACE TUG

Four general areas categorize the basic guidelines for deriving the actual payload weight values to determine the Agena space tug performance capability: (1) mission specification, (2) vehicle weights, (3) vehicle propulsion characteristics, and (4) performance constraints.

6.1.1 Missions

The mission definition specifies the initial and final orbit conditions, ΔV schedule, and associated coast times for the following reference cases:

- Synchronous Equatorial Mission
- 1982 Viking Mars Interplanetary Mission
- Low-Earth, Sun-Synchronous, Multiple-Orbit, 30-Day duration Mission

These missions are discussed in detail in par. 4.1.

6.1.2 Vehicle Weights

Vehicle weights specify the impulse and nonimpulse propellant loadings and, by defining the stage inert weight, specify the difference between vehicle burnout weight and payload weight. For the Agena space tug the weights are based upon the current baseline Agena configuration modified for the space shuttle application.

6.1.3 Propulsion Characteristics

From a performance standpoint the two propulsion parameters of interest are the specific impulse and engine thrust levels. The Agena space tug configurations that were analyzed include the use of the current engine and UDMH/IRFNA propellants at 290.8 sec I_{sp} and 16,100 pounds vacuum thrust, as well as UDMH/HDA propellants and engine improvements, which yield 310 sec I_{sp} and 17,400 pounds of vacuum thrust.

6.1.4 Constraints

The primary performance constraint is a maximum Agena space tug plus payload ignition weight limitation, corresponding to the 65,000-pound space shuttle delivery capability due east at a 100 nm circular orbit. The actual ignition weight limit is set by subtracting from the 65,000-pound space shuttle delivery capability the support structure necessary to hold the Agena in the space shuttle cargo bay. Another constraint is the use of a 100 nm circular parking orbit condition for space shuttle delivery and Agena space tug ignition conditions.

6.2 PAYLOAD CAPABILITY

The Agena space tug performance capability under the above guidelines is given in Table 6.1.

Table 6-1
AGENA SPACE TUG PAYLOAD CAPABILITY

Mission	Payload Weight (lb)	
	I_{sp} = 290.8 sec	I_{sp} = 310.0 sec
Synchronous-Equatorial	2,257	2,804
Interplanetary	3,540	4,225
Low Earth, Sun-Sync Orbit*	9,770 (Each Orbit)	10,053 (Each Orbit)

*Agena space tug payload performance is constrained by space shuttle payload capability for near-polar orbit.

All payload capability shown is based upon withholding a flight performance reserve of Agena propellant weight equivalent to 1 percent of the mission ΔV. The current Agena engine and UDMH/IRFNA propellants at 290.8 sec I_{sp} yields 2257 pounds of payload to synchronous-equatorial conditions, 3540 pounds of payload towards Mars on the 1982 Viking mission, and two payloads each weighing 9770 pounds in support of the low-earth, sun synchronous, 30-day duration mission. The effect of utilizing the high-density acid oxidizer that, with injector and nozzle improvements, raises the I_{sp} to 310 sec, is to produce 24 percent (547 pounds) increase into synchronous equatorial and a +19 percent (685 pounds) for the interplanetary mission. The 280-pound gain per payload for the low earth sun synchronous orbit comes about because of the redefined match point between shuttle delivery capability and Agena performance for this specific mission definition. The initial target orbit conditions for the 600 nm, circular, sun synchronous portion of the low earth orbit mission require an inclination angle of 99.88 deg. For Agena space tug initial conditions corresponding to 100 nm circular orbit and 99.88 deg inclination angle, the subsequent total mission ΔV sequence, together with the specified vehicle characteristics, results in a maximum capability ignition weight of 56,000 pounds for 290.8 sec I_{sp} and 62,000 pounds for 310 sec I_{sp}. Since the space shuttle delivery capability to a 100 nm circular orbit at 99.88 deg inclination angle is only 26,500 pounds, the maximum capability ignition weight of the Agena space tug and payload for these conditions would exceed the space shuttle delivery capability by 29,500 pounds and 35,500 pounds, respectively. Increasing the shuttle delivery capability by lowering the initial Agena space tug inclination angle also lowers the payload capability into the 600 and 400 nm circular orbits, since the ΔV requirements increase to change the new initial inclination angle to the required 99.88 deg. These relationships are illustrated in Fig. 6-1. The match points for shuttle capability and fully loaded Agena plus payload ignition weight occurs at 93.05 deg inclination angle and 34,660 pounds initial weight for Agena $I_{sp} = 290.8$ sec, and 92.27 deg and 35,650 pounds start weight for the 310 sec I_{sp} Agena. These conditions result in the aforementioned payload weights of 9770 pounds for 290.8 sec I_{sp} and the small gain of only 280 pounds, yielding 10,053 pounds for the 310 sec I_{sp} configuration.

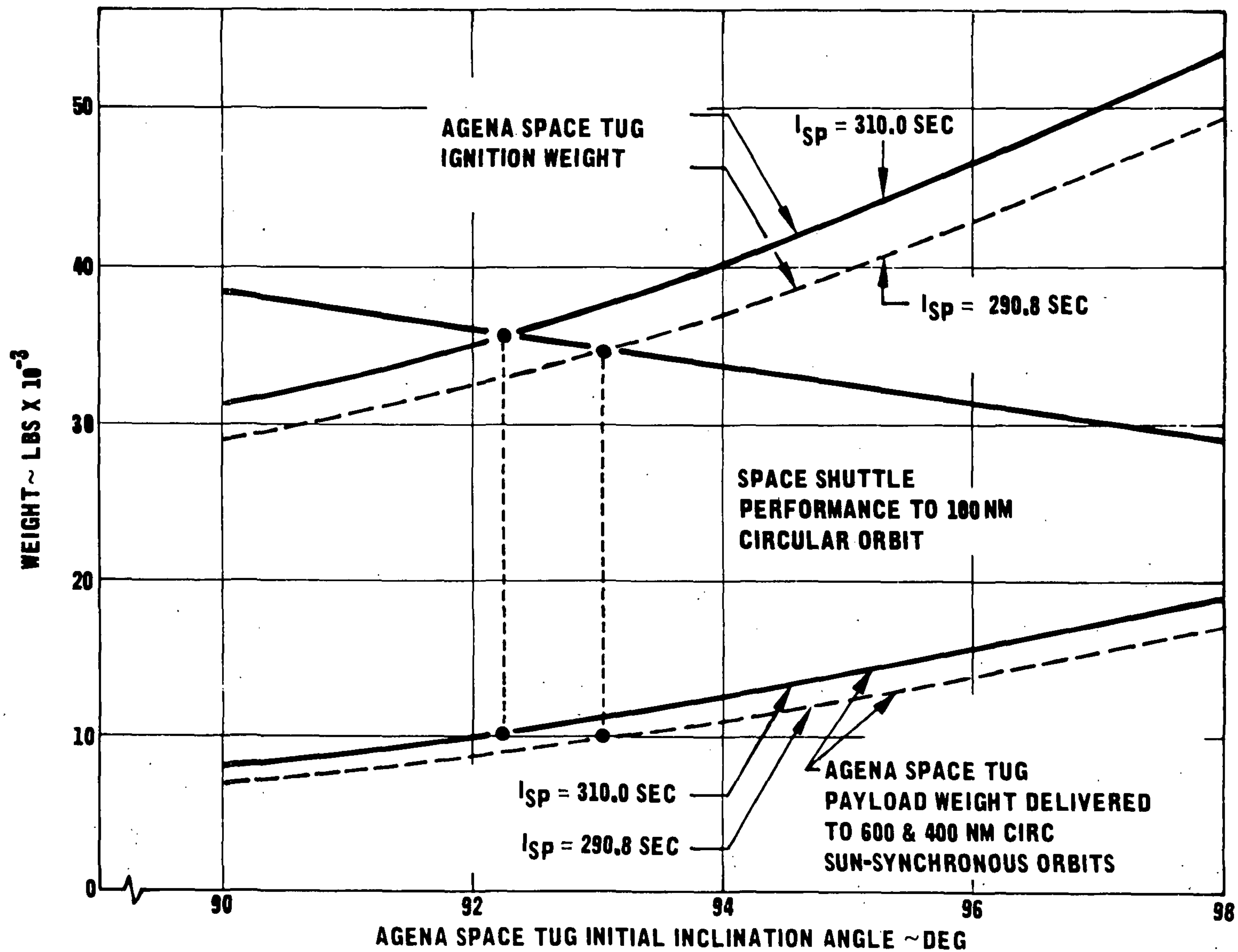


Fig. 6-1 Low-Earth-Orbit Mission Performance

6.2.1 Performance Simulations

Table 6-2 provides the data necessary to relate the Agena space tug inert weights shown in Tables 6-3 through 6-12 with the vehicle weights given in par. 2.3. For each mission and Agena space tug propellant combination, Tables 6-3 through 6-12 contain a typical example of the computer program printout that determined the individual payload weights. Included in the data are (1) a summary of parametric ΔV versus maximum payload weight capability, with and without an ignition weight constraint and the associated performance partials; (2) an online outboard profile of the Agena space tug in the space shuttle cargo bay including pertinent geometrical parameters and tank capacities; (3) an Agena space tug weight statement peculiar to each mission application, including a propulsion system characteristic summary; and (4) a mission description, sequence of events, and running weight sequences on propellant weight and absolute weight as well as weight losses, such as the transients between burns.

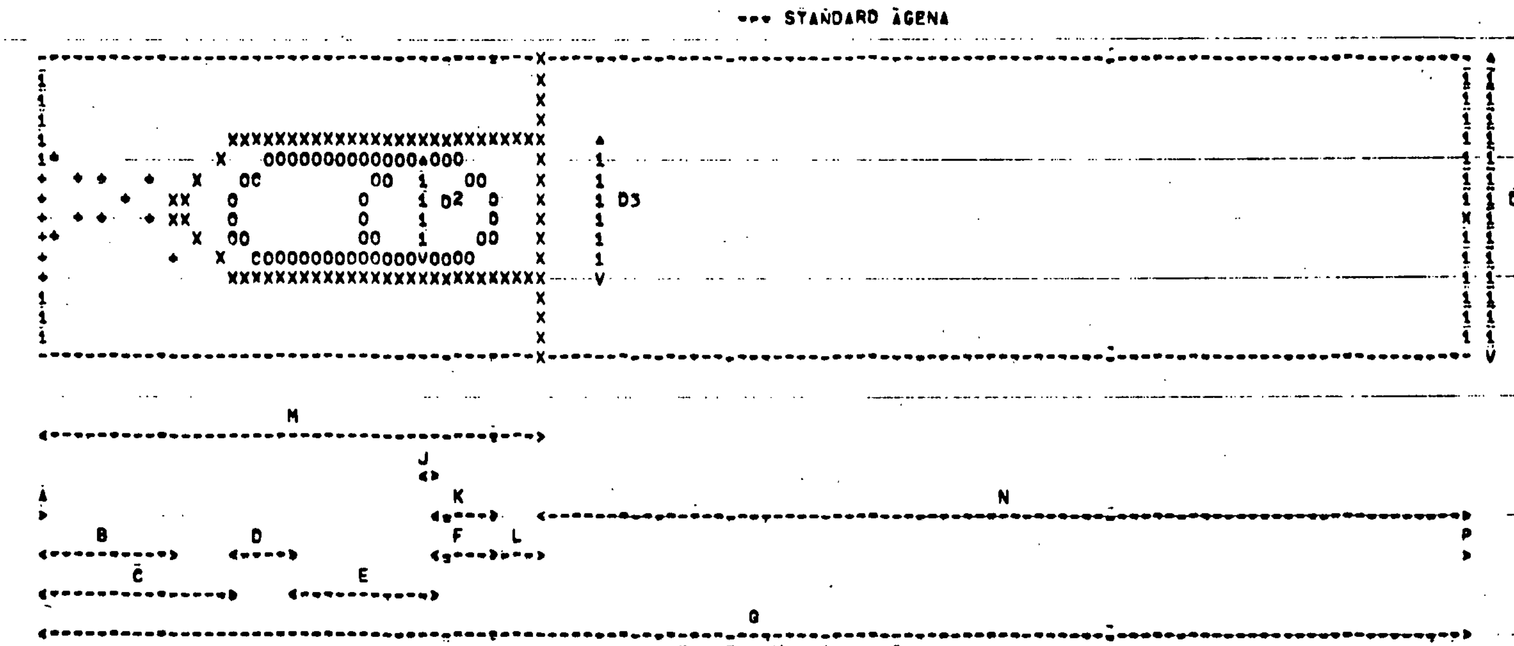
Table 6-2

SUMMARY OF PERFORMANCE-PERTINENT BASELINE VEHICLE WEIGHTS

	Synchronous-Equatorial Mission		Interplanetary Mission		Low-Earth-Orbit Mission	
	Agena I_{sp} = 290.8 sec	Agena I_{sp} = 310 sec	Agena I_{sp} = 290.8 sec	Agena I_{sp} = 310 sec	Agena I_{sp} = 290.8 sec	Agena I_{sp} = 310 sec
Dry Weight	1,369	1,396	1,273	1,300	1,489	1,516
Propellant Residuals	48	72	48	72	48	72
Pre-Flow	30	33	10	11	60	66
Post-Flow	135	141	45	47	270	282
Propellant Margin	57	62	63	68	140	135
Impulse Propellant	13,291	13,647	13,395	13,756	13,043	13,399
Helium Gas	3	3	3	3	3	3
N_2 Gas	30	30	30	30	78	78
Wet Weight	14,963	15,384	14,867	15,287	15,130	15,551
Impulse Propellant	13,291	13,647	13,395	13,756	13,043	13,399
Pre- & Post-Flow Propellant	165	174	55	58	330	348
Propellant Margin	57	62	63	68	140	135
N_2 Gas	8	9	8	8	68	73
Wet Weight at Burnout	1,442	1,492	1,346	1,397	1,550	1,596

Table 6-3

CANDIDATE AGENA SPACE TUG CONFIGURATION



BULK HEAD ELLIPSE RATIO IS 1.0000

PAYLOAD LENGTH (FT)	TANK TYPE	TANK LENGTH (FT)	HEAD VOL. (FT3)	CYL. VOL. (FT3)	TOTAL VOL. (FT3)	ULLAGE VOL. (FT3)	NET TANK LIQUID (FT3)	STORED LIQUID (LB)	RESIDUAL LIQUID (LB)	TOTAL IMPULSE (LB)	SPECIFIC IMPULSE (SEC)
39.06	FUEL	5.7	65.4	14.4	79.8	1.6	78.2	3841.6	13.6	3828.0	290.8
.00	OX	7.9	32.7	72.4	105.1	5.3	99.9	9719.3	34.4	9684.9	

GEOMETRY OF TANKS

DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q
IN FEET	.0	5.7	7.9	2.5	6.1	2.5	.0	.0	.0	.7	2.5	2.0	20.9	39.1	.0	60.0
IN INCHS	.0	68.4	94.8	30.0	73.1	30.0	.0	.0	.0	8.8	30.0	23.4	251.3	468.7	.0	720.0

DIMENSION	D1	D2	D3	D4
IN FEET	5.0	5.0	5.5	15.0
IN INCHS	60.0	60.0	66.0	180.0

Table 6-3 (cont)

ENGINE CHARACTERISTICS				
	PROPELLANT TYPE	MIXTURE RATIO (O/F)	OX DENSITY	FUEL DENSITY
MAIN ENGINE	UDMH/N02	2.53	97.3 LBS/FT3	49.1 LBS/FT3
REACTION CONTROL SYSTEM	N204/UDMH			

MAIN SYSTEM	
DESIGNATION	8096 BELL ENGINE (MULTI-START)
SOURCE	BELL AEROSPACE CORPORATION
OPERATING CONDITIONS	
VACUUM THRUST	16080. LBS
VACUUM SPECIFIC IMPULSE	290.8 SEC
FLOW RATE	55.3 LB/SEC
EXPANSION RATIO	55/1
MINIMUM BIT IMPULSE	23750. LB-SEC

Table 6-4

CANDIDATE AGENA SPACE TUG PERFORMANCE CAPABILITY (I_{sp} = 290.8 sec)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 2000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	70175.	13513.	55220.	0.	8.000	.000
FIXED IGN. WT.	65000.	12517.	51041.	0.	7.394	.000
REUSABLE/1	68289.	13513.	53334.	0.	7.726	.000
FIXED IGN. WT.	65000.	12880.	50678.	0.	7.342	.000
REUSABLE/2	38067.	13513.	23112.	23112.	3.348	3.348
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	14955.	13513.	0.	40786.	.000	5.909
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.216+03	.218+03	.000	.143+03	.143+03	.000	.317+03
ΔU1	-.238+06	-.231+06	.000	-.559+05	-.559+05	.000	-.387+05
ΔU2	-.749+04	-.749+04	.000	-.553+05	-.553+05	.000	-.168+06
ΔDV1	-.315+02	-.306+02	.000	-.740+01	-.740+01	.000	-.513+01
ΔDV2	-.801+00	-.100+01	.000	-.740+01	-.740+01	.000	-.225+02
ΔWI	-.100+01	-.231+01	.000	-.100+01	-.100+01	.000	-.176+01
ΔWP	.419+01	.419+01	.000	.182+01	.182+01	.000	.321+01
ΔR	.000	.697+05	-.224+06	.524+05	-.401+05	.408+05	-.312+05

ON ORBIT VELOCITY = 4000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	38825.	13513.	23870.	0.	3.458	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	36545.	13513.	21590.	0.	3.128	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	23319.	13513.	8364.	8364.	1.212	1.212
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	14955.	13513.	0.	13654.	.000	1.978
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.107+03	.110+03	.000	.641+02	.641+02	.000	.127+03
ΔU1	-.474+05	-.446+05	.000	-.110+05	-.110+05	.000	-.116+05
ΔU2	-.414+04	-.414+04	.000	-.109+05	-.109+05	.000	-.274+05
ΔDV1	-.778+01	-.732+01	.000	-.181+01	-.181+01	.000	-.189+01
ΔDV2	-.443+00	-.687+00	.000	-.181+01	-.181+01	.000	-.455+01
ΔWI	-.100+01	-.258+01	.000	-.100+01	-.100+01	.000	-.163+01
ΔWP	.187+01	.187+01	.000	.726+00	.726+00	.000	.118+01
ΔR	.000	.341+05	-.404+05	.205+05	-.130+05	.137+05	-.864+04

Table 6-4 (cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 6000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	28533.	13513.	13578.	0.	1.967	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	25732.	13513.	10777.	0.	1.561	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	18617.	13513.	3662.	3662.	.531	.531
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	14955.	13513.	0.	5547.	.000	.804
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.700+02	.762+02	.000	.371+02	.371+02	.000	.649+02
ΔU1	-.167+05	-.151+05	.000	-.370+04	-.370+04	.000	-.490+04
ΔU2	-.305+04	-.305+04	.000	-.366+04	-.366+04	.000	-.760+04
ΔDV1	-.339+01	-.306+01	.000	-.752+00	-.752+00	.000	-.915+00
ΔDV2	-.326+00	-.625+00	.000	-.752+00	-.752+00	.000	-.156+01
ΔWI	-.100+01	-.294+01	.000	-.100+01	-.100+01	.000	-.151+01
ΔWP	.111+01	.111+01	.000	.378+00	.378+00	.000	.572+00
ΔR	.000	.209+05	-.120+05	.967+04	-.498+04	.555+04	-.286+04

ON ORBIT VELOCITY = 8000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	23503.	13513.	8548.	0.	1.238	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	20046.	13513.	5091.	0.	.738	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	16454.	13513.	1499.	1499.	.217	.217
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	14955.	13513.	0.	2124.	.000	.308
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.511+02	.614+02	.000	.235+02	.235+02	.000	.364+02
ΔU1	-.739+04	-.630+04	.000	-.152+04	-.152+04	.000	-.196+04
ΔU2	-.251+04	-.251+04	.000	-.151+04	-.151+04	.000	-.259+04
ΔDV1	-.186+01	-.158+01	.000	-.383+00	-.383+00	.000	-.493+00
ΔDV2	-.268+00	-.638+00	.000	-.383+00	-.383+00	.000	-.658+00
ΔWI	-.100+01	-.340+01	.000	-.100+01	-.100+01	.000	-.142+01
ΔWP	.739+00	.739+00	.000	.218+00	.218+00	.000	.308+00
ΔR	.000	.122+05	-.376+04	.423+04	-.177+04	.212+04	-.886+03

Table 6-4 (cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 10000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	20574.	13513.	5619.	0.	.814	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	16303.	13513.	1348.	0.	.195	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	15295.	13513.	340.	340.	.049	.049
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	14955.	13513.	0.	455.	.000	.066
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.395+02	.553+02	.000	.154+02	.154+02	.000	.212+02
ΔU1	-.369+04	-.292+04	.000	-.692+03	-.692+03	.000	-.906+03
ΔU2	-.220+04	-.220+04	.000	-.685+03	-.685+03	.000	-.975+03
ΔDV1	-.115+01	-.911+00	.000	-.216+00	-.216+00	.000	-.282+00
ΔDV2	-.235+00	-.692+00	.000	-.216+00	-.216+00	.000	-.307+00
ΔWI	-.100+01	-.396+01	.000	-.100+01	-.100+01	.000	-.134+01
ΔWP	.523+00	.523+00	.000	.132+00	.132+00	.000	.176+00
ΔR	.000	.399+04	-.704+03	.102+04	-.344+03	.455+03	-.154+03

ON ORBIT VELOCITY = 12000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	18693.	13513.	3738.	0.	.542	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	13412.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	14624.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	14955.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.316+02	.551+02	.000	.102+02	.102+02	.000	.125+02
ΔU1	-.199+04	-.142+04	.000	-.333+03	-.333+03	.000	-.434+03
ΔU2	-.199+04	-.199+04	.000	-.330+03	-.330+03	.000	-.386+03
ΔDV1	-.766+00	-.550+00	.000	-.129+00	-.129+00	.000	-.167+00
ΔDV2	-.213+00	-.778+00	.000	-.129+00	-.129+00	.000	-.150+00
ΔWI	-.100+01	-.466+01	.000	-.100+01	-.100+01	.000	-.127+01
ΔWP	.383+00	.383+00	.000	.822-01	.822-01	.000	.105+00
ΔR	.000	-.565+04	.592+03	-.104+04	.284+03	-.421+03	.115+03

Table 6-4 (cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 14100. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	17355.	13513.	2400.	0.	.348	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	10750.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	14202.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	14955.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.256+02	.600+02	.000	.663+01	.663+01	.000	.698+01
ΔU1	-.109+04	-.677+03	.000	-.160+03	-.160+03	.000	-.206+03
ΔU2	-.185+04	-.185+04	.000	-.158+03	-.158+03	.000	-.147+03
ΔDV1	-.528+00	-.327+00	.000	-.774-01	-.774-01	.000	-.993-01
ΔDV2	-.198+00	-.904+00	.000	-.774-01	-.774-01	.000	-.718-01
ΔWI	-.100+01	-.558+01	.000	-.100+01	-.100+01	.000	-.122+01
ΔWP	.284+00	.284+00	.000	.510-01	.510-01	.000	.621-01
ΔR	.000	-.193+05	.120+04	-.247+04	.540+03	-.918+03	.200+03

ON ORBIT VELOCITY = 16000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	16493.	13513.	1538.	0.	.223	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	8406.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	13964.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	14955.	13513.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.214+02	.692+02	.000	.442+01	.442+01	.000	.394+01
ΔU1	-.657+03	-.335+03	.000	-.842+02	-.842+02	.000	-.106+03
ΔU2	-.176+04	-.176+04	.000	-.833+02	-.833+02	.000	-.597+02
ΔDV1	-.389+00	-.198+00	.000	-.498-01	-.498-01	.000	-.629-01
ΔDV2	-.188+00	-.105+01	.000	-.498-01	-.498-01	.000	-.357-01
ΔWI	-.100+01	-.661+01	.000	-.100+01	-.100+01	.000	-.118+01
ΔWP	.221+00	.221+00	.000	.334-01	.334-01	.000	.393-01
ΔR	.000	-.367+05	.144+04	-.336+04	.600+03	-.117+04	.208+03

Table 6-5

AGENA SPACE TUG SEQUENCE OF EVENTS AND WEIGHTS FOR SYNCHRONOUS-EQUATORIAL MISSION (I_{sp} = 290.8 sec)

SYNCHRONOUS EQUATORIAL --- STANDARD AGENA

SYNCHRONOUS EQUATORIAL MISSION
INITIAL CONDITIONS 100NM CIRC, 28.3 DEG INC EARTH ORBIT
TARGET CONDITIONS 19330NM CIRC, 0 DEG INC EARTH ORBIT
FINAL CONDITIONS

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XFER OPT INCL SPLIT
RETURN FLIGHT PROFILE
STAY TIME AT TARGET
PAYLOAD LENGTH 39.1 FT
PAYLOAD DELIVERED TO TARGET 2257. PAYLOAD DENSITY .024 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON 0. PAYLOAD DENSITY .000 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 13348. RCS PROPELLANT 8.108
WET INERT WEIGHT 1442. MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	SPACE TUG DEPLOY (INCL=28.3)	0: 0: .0			17220.4		13348.0
			0.	RCS		.0	
		0: 0: .0			17220.4		13348.0
						10.0	
	PHASING ORBIT INJ (INCL=26.1)	0: 0:30.0			17210.4		13348.0
			7932.	MAIN		9816.1	
		0: 0:33.0			7394.4		3531.9
						45.0	
	ENGINE POST FLOW	0: 0:33.0			7349.4		3531.9
			0.	MAIN		.0	
		0: 0:33.0			7349.4		3531.9
						10.0	
	XFER ORBIT INJ (INCL=26.1)	0: 9:41.0			7339.4		3531.9
			260.	MAIN		200.0	
		0: 9:41.0			7139.3		3331.9
						45.0	
	MIDCOURSE + ATTITUDE CONTROL	0:10:23.0			7094.3		3331.9
			12.	RCS		8.1	
		0:10:23.5			7086.2		3331.9
						10.0	
	SYN EQ INJ (INCL=0.0)	0:14:52.5			7076.2		3331.9
			5865.	MAIN		3276.1	
		0:14:53.4			3800.2		55.8
						45.0	
	FLIGHT PERFORMANCE RESERVES	0:14:53.4			3755.2		55.8
TARGET 1			140.	MAIN		55.8	
		0:14:53.5			3699.4		-.0

Table 6-5 (cont)

SYNCHRONOUS EQUATORIAL --- STANDARD AGENA

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	370.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	608.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	166.		0.	1)	A)
T T AND C	46.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	180.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1369.		0.		

Table 6-6

AGENA SPACE TUG SEQUENCE OF EVENTS AND WEIGHTS FOR INTERPLANETARY MISSION
(I_{sp} = 290.8 sec)

INTERPLANETARY INJ ---- STANDARD AGENA

```
1982 VIKING MISSION
  INITIAL CONDITIONS  100NM CIRC, 28.3 DEG INC EARTH ORBIT
  TARGET  CONDITIONS  TRANS MARS INJECTION
  FINAL   CONDITIONS

  COMMENTS
    OUTBOUND FLIGHT PROFILE    10 DAY LAUNCH PERIOD
    RETURN FLIGHT PROFILE
    STAY TIME AT TARGET
    PAYLOAD LENGTH                39.1 FT
    PAYLOAD DELIVERED TO TARGET        3540.    PAYLOAD DENSITY     .008 LB/FT3    BASED ON D4
    PAYLOAD RETURNED TO FINAL CON         0.    PAYLOAD DENSITY     .000 LB/FT3    BASED ON D4
    IMPULSE PROPELLANT                13458.    RCS PROPELLANT      8.005
    WET INERT WEIGHT                   1346.
```

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	TUG DEPLOY, FROM SPACE SHUTTLE	01 01 .0			18407.1		13458.0
			4.	RCS		8.0	
		01 01 .4			18399.1		13458.0
						10.0	
	TRANS-MARS INJECTION	01 0:30.4			18389.1		13458.0
			12250.	MAIN		13394.9	
		01 0:34.5			4994.3		63.1
						45.0	
	FLIGHT PERFORMANCE RESERVE	01 0:34.5			4949.3		63.1
TARGET 1			120.	MAIN		63.1	
		01 0:34.5			4886.1		-.0

Table 6-6 (cont)

INTERPLANETARY INJ ---- STANDARD AGENA

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	370.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	608.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	166.		0.	1)	A)
T T AND C	37.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	93.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1273.		0.		

Table 6-7

AGENA SPACE TUG SEQUENCE OF EVENTS AND WEIGHTS FOR LOW-EARTH-ORBIT MISSION (I_{sp} = 290.8 sec)

SUN SYNC (30 DAY MISSION) --- STANDARD AGENA

SUN SYNCHRONOUS MISSION
INITIAL CONDITIONS 100NM CIR, 93.05 DEG INC EARTH ORBIT
TARGET CONDITIONS TARGET 1- 600NM CIR, 99.884 DEG INC TARGET 2- 400NM CIR, 98.262 DEG INC
FINAL CONDITIONS 100 NM CIRC 98.262 DEG INCL

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XSFER OPT INC SPLIT
RETURN FLIGHT PROFILE HOHMANN TRANSFER
STAY TIME AT TARGET 1.3 REV <-- 29DAYS
PAYLOAD LENGTH 39.1 FT
PAYLOAD DELIVERED TO TARGET 9770. PAYLOAD DENSITY 2.878 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON 9770. PAYLOAD DENSITY 1.415 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 13183. RCS PROPELLANT 59.598
WET INERT WEIGHT 1550. MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	SPACE TUG DEPLOY (INCL=93.05)	0: 0: .0			34662.7		13183.0
			0.	RCS		.0	
		0: 0: .0			34662.7		13183.0
						10.0	
	XSFER ORBIT INJ (INCL=95.61)	0: 0:30.0			34652.7		13183.0
			1435.	MAIN		4923.5	
		0: 0:31.5			29728.5		8259.4
						45.0	
	MIDCOURSE + ATTITUDE CONTROL	0: 0:56.3			29683.5		8259.4
			7.	RCS		21.5	
		0: 0:57.4			29662.0		8259.4
						10.0	
	INJ 600NM CIR ORB (INC=99.884)	0: 1:21.4			29652.0		8259.4
			1915.	MAIN		5482.9	
		0: 1:23.1			24169.7		2776.6
						45.0	
	FLIGHT PERFORMANCE RESERVE	0: 1:23.1			24124.7		2776.6
TARGET 1			45.	MAIN		115.8	
		0: 1:23.1			24008.9		2660.7
						9779.5	
	XSFER ORBIT INJ (INCL = 99.04)	0: 3:40.6			14228.7		2660.7
			465.	MAIN		687.8	
		0: 3:40.8			13540.9		1972.9
						45.0	
	MIDCOURSE + ATTITUDE CONTROL	0: 4: 7.6			13495.9		1972.9
			5.	RCS		7.1	
		0: 4: 8.0			13488.8		1972.9
						10.0	
	INJ 400NM CIR ORB (INC=98.262)	0: 4:33.0			13478.8		1972.9
			456.	MAIN		639.8	
		0: 4:33.2			12839.0		1333.1
						45.0	
	FLIGHT PERFORMANCE RESERVE	0: 4:33.2			12794.0		1333.1
TARGET 2			9.	MAIN		12.3	
		0: 4:33.2			12781.7		1320.8
						10.0	
	XSFER ORBIT INJ (INCL= 98.262)	29: 4:33.2			12771.7		1320.8
			504.	MAIN		667.8	
		29: 4:33.4			12103.8		653.0

Table 6-7 (Cont)

						45.0	
	MIDCOURSE + ATTITUDE CONTROL	291 4:57.2			12058.8		653.0
			27.	RCS		30.9	
		291 4:58.9			12027.9		653.0
						10.0	
	INJ 100NM CIR ORB (INC=98.262)	291 5:21.9			12017.9		653.0
			514.	MAIN		640.8	
		291 5:22.1			11377.1		12.1
						45.0	
	FLIGHT PERFORMANCE RESERVE	291 5:22.1			11332.1		12.1
FINAL			10.	MAIN		12.1	
		291 5:22.1			11319.9		-.0

Table 6-7 (Cont)

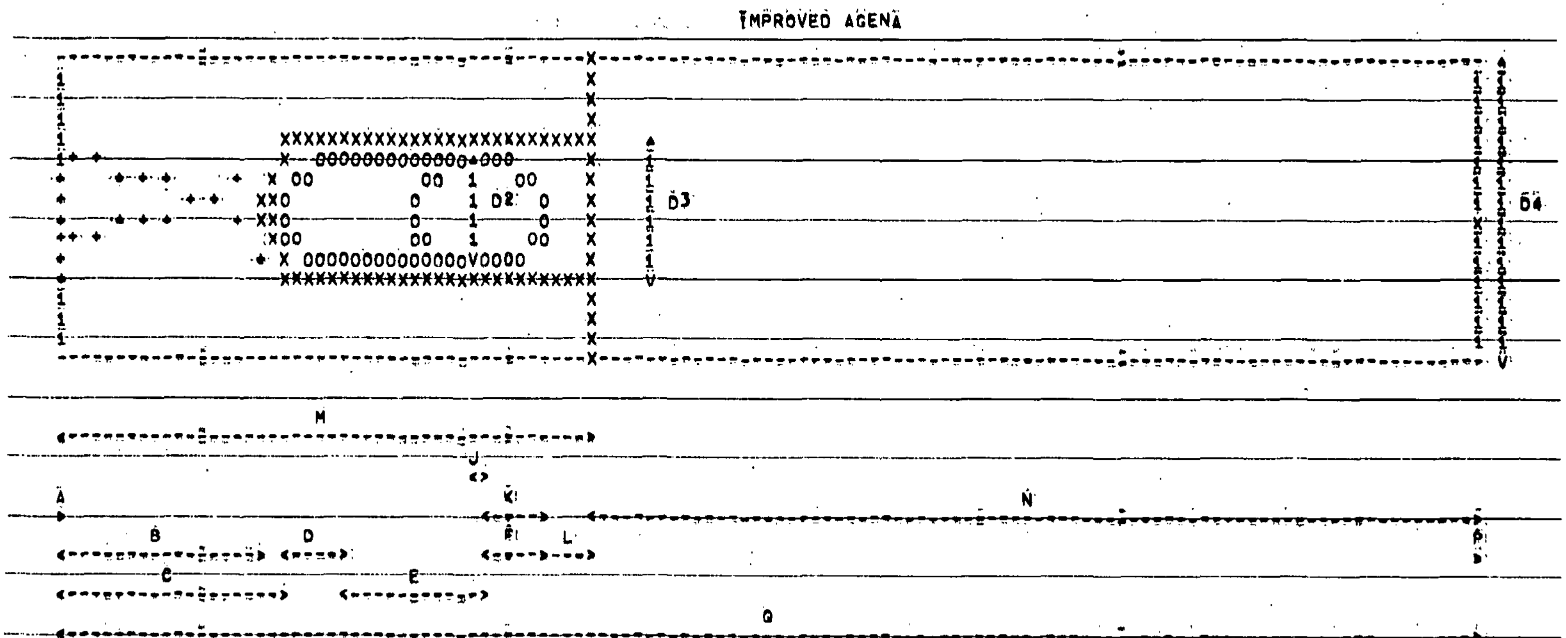
SUN SYNC (30 DAY MISSION) --- STANDARD AGENA

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	370.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	567.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	350.		0.	1)	A)
T T AND C	37.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	166.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1489.		0.		

Table 6-8

AGENA SPACE TUG CONFIGURATION – IMPROVED PROPULSION SYSTEM (I_{sp} = 310 sec)



BULK HEAD ELLIPSE RATIO IS 1.0000

PAYLOAD LENGTH (FT)	TANK TYPE	TANK LENGTH (FT)	HEAD VOL. (FT3)	CYL. VOL. (FT3)	TOTAL VOL. (FT3)	ULLAGE VOL. (FT3)	NET TANK LIQUID (FT3)	STORED LIQUID (LB)	RESIDUAL LIQUID (LB)	TOTAL IMPULSE (LB)	SPECIFIC IMPULSE (SEC)
37.47	FUEL	5.7	65.4	13.9	79.4	1.6	77.8	3819.9	19.7	3800.2	310.0
.00	OX	7.8	32.7	72.3	105.0	5.3	99.8	10134.2	52.3	10081.9	

GEOMETRY OF TANKS

DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q
IN FEET	.0	8.6	9.5	2.5	6.1	2.5	.0	.0	.0	.7	2.5	2.0	22.5	37.5	.0	60.0
IN INCHS	.0	103.2	114.2	30.0	72.7	30.0	.0	.0	.0	8.5	30.0	23.4	270.3	449.7	.0	720.0

DIMENSION	D1	D2	D3	D4
IN FEET	5.0	5.0	5.5	15.0
IN INCHS	60.0	60.0	66.0	180.0

Table 6-8 (Cont)

ENGINE CHARACTERISTICS

	PROPELLANT TYPE	MIXTURE RATIO (O/F)	OX DENSITY	FUEL DENSITY
MAIN ENGINE	UDMH/HDA	2.653	101.58 LBS/FT3	49.1 LBS/FT3
REACTION CONTROL SYSTEM	N204/UDMH			

MAIN SYSTEM	
DESIGNATION	8096 BELL ENGINE (MULTI-START)
SOURCE	BELL AEROSPACE CORPORATION

OPERATING CONDITIONS	
VACUUM THRUST	17620. LBS
VACUUM SPECIFIC IMPULSE	310.0 SEC
FLOW RATE	56.9 LB/SEC
EXPANSION RATIO	55/1
MINIMUM BIT IMPULSE	23750. LB-SEC

Table 6-9

AGENA SPACE TUG PERFORMANCE CAPABILITY – (I_{sp} = 310 sec)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 2000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	76361.	13882.	60987.	0.	9.209	.000
FIXED IGN. WT.	65000.	11817.	51691.	0.	7.806	.000
REUSABLE/1	74436.	13882.	59062.	0.	8.919	.000
FIXED IGN. WT.	65000.	12167.	51341.	0.	7.753	.000
REUSABLE/2	41166.	13882.	25792.	25792.	3.895	3.895
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	15374.	13882.	0.	45786.	.000	6.914
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.222+03	.224+03	.000	.147+03	.147+03	.000	.330+03
ΔU1	-.281+06	-.274+06	.000	-.662+05	-.662+05	.000	-.439+05
ΔU2	-.821+04	-.821+04	.000	-.655+05	-.655+05	.000	-.202+06
ΔDV1	-.345+02	-.336+02	.000	-.812+01	-.812+01	.000	-.538+01
ΔDV2	-.823+00	-.102+01	.000	-.812+01	-.812+01	.000	-.250+02
ΔWI	-.100+01	-.229+01	.000	-.100+01	-.100+01	.000	-.178+01
ΔWP	.450+01	.450+01	.000	.197+01	.197+01	.000	.349+01
ΔR	.000	.762+05	-.266+06	.581+05	-.451+05	.458+05	-.355+05

ON ORBIT VELOCITY = 4000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	41998.	13882.	26624.	0.	4.020	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	39701.	13882.	24327.	0.	3.673	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	24954.	13882.	9580.	9580.	1.447	1.447
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	15374.	13882.	0.	15804.	.000	2.386
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.110+03	.113+03	.000	.669+02	.669+02	.000	.134+03
ΔU1	-.569+05	-.538+05	.000	-.133+05	-.133+05	.000	-.135+05
ΔU2	-.451+04	-.451+04	.000	-.132+05	-.132+05	.000	-.340+05
ΔDV1	-.853+01	-.807+01	.000	-.200+01	-.200+01	.000	-.203+01
ΔDV2	-.453+00	-.683+00	.000	-.200+01	-.200+01	.000	-.515+01
ΔWI	-.100+01	-.254+01	.000	-.100+01	-.100+01	.000	-.165+01
ΔWP	.203+01	.203+01	.000	.798+00	.798+00	.000	.132+01
ΔR	.000	.374+05	-.493+05	.232+05	-.151+05	.158+05	-.103+05

Table 6-9 (Cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 6000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	30696.	13882.	15322.	0.	2.314	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	27911.	13882.	12537.	0.	1.893	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	19748.	13882.	4374.	4374.	.660	.660
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	15374.	13882.	0.	6717.	.000	1.014
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REJSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.722+02	.777+02	.000	.392+02	.392+02	.000	.702+02
ΔU1	-.204+05	-.185+05	.000	-.457+04	-.457+04	.000	-.547+04
ΔU2	-.330+04	-.330+04	.000	-.453+04	-.453+04	.000	-.973+04
ΔDV1	-.373+01	-.339+01	.000	-.837+00	-.837+00	.000	-.100+01
ΔDV2	-.331+00	-.610+00	.000	-.837+00	-.837+00	.000	-.180+01
ΔWI	-.100+01	-.287+01	.000	-.100+01	-.100+01	.000	-.154+01
ΔWP	.121+01	.121+01	.000	.423+00	.423+00	.000	.649+00
ΔR	.000	.234+05	-.152+05	.114+05	-.610+04	.672+04	-.360+04

ON ORBIT VELOCITY = 8000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	25157.	13882.	9782.	0.	1.477	.000
FIXED IGN. WT.	65000.	0.	0.	-0.	.000	.000
REUSABLE/1	21766.	13882.	6392.	0.	.965	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	17328.	13882.	1954.	1954.	.295	.295
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	15374.	13882.	0.	2813.	.000	.425
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REJSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.529+02	.617+02	.000	.252+02	.252+02	.000	.403+02
ΔU1	-.916+04	-.792+04	.000	-.193+04	-.193+04	.000	-.246+04
ΔU2	-.270+04	-.270+04	.000	-.191+04	-.191+04	.000	-.343+04
ΔDV1	-.205+01	-.177+01	.000	-.431+00	-.431+00	.000	-.551+00
ΔDV2	-.271+00	-.611+00	.000	-.431+00	-.431+00	.000	-.776+00
ΔWI	-.100+01	-.327+01	.000	-.100+01	-.100+01	.000	-.144+01
ΔWP	.812+00	.812+00	.000	.248+00	.248+00	.000	.357+00
ΔR	.000	.145+05	-.519+04	.543+04	-.239+04	.281+04	-.124+04

Table 6-9 (Cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 10000. FPS

MISSION MODE	IGNITION WT. LB	PROPELLANT WT. LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN. LB/FT3	P/L RET. DEN. LB/FT3
EXPENDABLE	21920.	13882.	6546.	0.	.988	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	17786.	13882.	2412.	0.	.364	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	16014.	13882.	640.	640.	.097	.097
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	15374.	13882.	0.	871.	.000	.131
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.411+02	.545+02	.000	.169+02	.169+02	.000	.241+02
ΔU1	-.465+04	-.378+04	.000	-.902+03	-.902+03	.000	-.118+04
ΔU2	-.236+04	-.236+04	.000	-.893+03	-.893+03	.000	-.135+04
ΔDV1	-.127+01	-.103+01	.000	-.247+00	-.247+00	.000	-.322+00
ΔDV2	-.236+00	-.651+00	.000	-.247+00	-.247+00	.000	-.372+00
ΔWI	-.100+01	-.377+01	.000	-.100+01	-.100+01	.000	-.136+01
ΔWP	.579+00	.579+00	.000	.154+00	.154+00	.000	.209+00
ΔR	.000	.668+04	-.140+04	.188+04	-.679+03	.871+03	-.314+03

ON ORBIT VELOCITY = 12000. FPS

MISSION MODE	IGNITION WT. LB	PROPELLANT WT. LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN. LB/FT3	P/L RET. DEN. LB/FT3
EXPENDABLE	19833.	13882.	4458.	0.	.673	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/1	14787.	13882.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	15240.	13882.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	15374.	13882.	0.	0.	.000	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.330+02	.527+02	.000	.115+02	.115+02	.000	.146+02
ΔU1	-.255+04	-.190+04	.000	-.447+03	-.447+03	.000	-.585+03
ΔU2	-.213+04	-.213+04	.000	-.443+03	-.443+03	.000	-.557+03
ΔDV1	-.853+00	-.636+00	.000	-.150+00	-.150+00	.000	-.196+00
ΔDV2	-.214+00	-.720+00	.000	-.150+00	-.150+00	.000	-.188+00
ΔWI	-.100+01	-.438+01	.000	-.100+01	-.100+01	.000	-.130+01
ΔWP	.429+00	.429+00	.000	.978-01	.978-01	.000	.127+00
ΔR	.000	-.198+04	.252+03	-.414+03	.122+03	-.174+03	.514+02

Table 6-9 (Cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 14100. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL, DEN, LB/FT3	P/L RET, DEN, LB/FT3
EXPENDABLE	18339.	13882.	2965.	0.	.448	.000
FIXED IGN, WT,	65000.	0.	0.	0.	.000	.000
REUSABLE/1	12118.	13882.	0.	0.	.000	.000
FIXED IGN, WT,	65000.	0.	0.	0.	.000	.000
REUSABLE/2	14744.	13882.	0.	0.	.000	.000
FIXED IGN, WT,	65000.	0.	0.	0.	.000	.000
REUSABLE/3	15374.	13882.	0.	0.	.000	.000
FIXED IGN, WT,	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.269+02	.554+02	.000	.765+01	.765+01	.000	.858+01
ΔU1	-.143+04	-.946+03	.000	-.223+03	-.223+03	.000	-.288+03
ΔU2	-.197+04	-.197+04	.000	-.220+03	-.220+03	.000	-.225+03
ΔDV1	-.591+00	-.390+00	.000	-.919-01	-.919-01	.000	-.119+00
ΔDV2	-.198+00	-.822+00	.000	-.919-01	-.919-01	.000	-.939-01
ΔWI	-.100+01	-.517+01	.000	-.100+01	-.100+01	.000	-.124+01
ΔWP	.321+00	.321+00	.000	.621-01	.621-01	.000	.770-01
ΔR	.000	-.136+05	.105+04	-.203+04	.488+03	-.781+03	.187+03

ON ORBIT VELOCITY = 16000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL, DEN, LB/FT3	P/L RET, DEN, LB/FT3
EXPENDABLE	17371.	13882.	1997.	0.	.302	.000
FIXED IGN, WT,	65000.	0.	0.	0.	.000	.000
REUSABLE/1	9848.	13882.	0.	0.	.000	.000
FIXED IGN, WT,	65000.	0.	0.	0.	.000	.000
REUSABLE/2	14460.	13882.	0.	0.	.000	.000
FIXED IGN, WT,	65000.	0.	0.	0.	.000	.000
REUSABLE/3	15374.	13882.	0.	0.	.000	.000
FIXED IGN, WT,	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.226+02	.617+02	.000	.527+01	.527+01	.000	.514+01
ΔU1	-.877+03	-.497+03	.000	-.121+03	-.121+03	.000	-.154+03
ΔU2	-.187+04	-.187+04	.000	-.120+03	-.120+03	.000	-.983+02
ΔDV1	-.438+00	-.248+00	.000	-.604-01	-.604-01	.000	-.769-01
ΔDV2	-.187+00	-.942+00	.000	-.604-01	-.604-01	.000	-.496-01
ΔWI	-.100+01	-.604+01	.000	-.100+01	-.100+01	.000	-.120+01
ΔWP	.251+00	.251+00	.000	.416-01	.416-01	.000	.499-01
ΔR	.000	-.279+05	.139+04	-.305+04	.606+03	-.110+04	.217+03

Table 6-10

AGENA SPACE TUG SEQUENCE OF EVENTS AND WEIGHTS FOR SYNCHRONOUS-EQUATORIAL MISSION

(I_{sp} = 310 sec)

```
                    SYNCHRONOUS EQUATORIAL --- IMPROVED AGENA

SYNCHRONOUS EQUATORIAL MISSION
   INITIAL CONDITIONS  100NM CIRC, 28.3 DEG INC EARTH ORBIT
   TARGET  CONDITIONS  19330NM CIRC, 0 DEG INC EARTH ORBIT
   FINAL   CONDITIONS

   COMMENTS
      OUTBOUND FLIGHT PROFILE    HOHMANN XFER OPT INCL SPLIT
      RETURN FLIGHT PROFILE
      STAY TIME AT TARGET
      PAYLOAD LENGTH                37.5 FT
      PAYLOAD DELIVERED TO TARGET        2804.    PAYLOAD DENSITY      .026 LB/FT3      BASED ON D4
      PAYLOAD RETURNED TO FINAL CON         0.    PAYLOAD DENSITY      .000 LB/FT3      BASED ON D4
      IMPULSE PROPELLANT                13708.    RCS PROPELLANT      8.884
      WET INERT WEIGHT                   1492.              MISSION SEQUENCE
```

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	SPACE TUG DEPLOY (INCL=28.3)	0: 0: .0			18186.8		13708.1
			0.	RCS		.0	
		0: 0: .0			18186.8		13708.1
						11.0	
	PHASING ORBIT INJ (INCL=26.1)	0: 0:30.0			18175.8		13708.1
			7932.	MAIN		9948.3	
		0: 0:32.9			8227.5		3759.8
						47.0	
	ENGINE POST FLOW	0: 0:32.9			8180.5		3759.8
			0.	MAIN		.0	
		0: 0:32.9			8180.5		3759.8
						11.0	
	XFER ORBIT INJ (INCL=26.1)	0: 9:40.9			8169.5		3759.8
			260.	MAIN		209.1	
		0: 9:41.0			7960.4		3550.7
						47.0	
	MIDCOURSE + ATTITUDE CONTROL	0:10:23.0			7913.4		3550.7
			12.	RCS		8.9	
		0:10:23.5			7904.5		3550.7
						11.0	
	SYN EQ INJ (INCL=0.0)	0:14:52.5			7893.5		3550.7
			5865.	MAIN		3489.9	
		0:14:53.5			4403.6		60.8
						47.0	
	FLIGHT PERFORMANCE RESERVES	0:14:53.5			4356.6		60.8
TARGET 1			140.	MAIN		60.8	
		0:14:53.5			4295.8		-.0

Table 6-10 (Cont)

SYNCHRONOUS EQUATORIAL --- IMPROVED AGENA

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	397.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	608.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	166.		0.	1)	A)
T T AND C	46.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	180.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1396.		0.		

Table 6-11

AGENA SPACE TUG SEQUENCE OF EVENTS AND WEIGHTS FOR INTERPLANETARY MISSION (I_{sp} = 310 sec)

INTERPLANETARY INJ ---- IMPROVED AGENA

1982 VIKING MISSION
INITIAL CONDITIONS 100NM CIRC, 28.3 DEG INC EARTH ORBIT
TARGET CONDITIONS TRANS MARS INJECTION
FINAL CONDITIONS

COMMENTS
OUTBOUND FLIGHT PROFILE 10 DAY LAUNCH PERIOD
RETURN FLIGHT PROFILE
STAY TIME AT TARGET
PAYLOAD LENGTH 37.5 FT
PAYLOAD DELIVERED TO TARGET 4225. PAYLOAD DENSITY .009 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON 0. PAYLOAD DENSITY .000 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 13824. RCS PROPELLANT 7.995
WET INERT WEIGHT 1397.

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	TUG DEPLOY, FROM SPACE SHUTTLE	0: 0: .0			19512.0		13824.1
			4.	RCS		8.0	
		0: 0: .4			19504.0		13824.1
						11.0	
	TRANS-MARS INJECTION	0: 0:30.4			19493.0		13824.1
			12250.	MAIN		13756.0	
		0: 0:34.5			5737.0		68.1
						47.0	
	FLIGHT PERFORMANCE RESERVE	0: 0:34.5			5690.0		68.1
TARGET 1			120.	MAIN		68.1	
		0: 0:34.5			5621.9		-.0

Table 6-11 (Cont)

INTERPLANETARY INJ ---- IMPROVED AGENA

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	397.		0.	I)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	608.		0.	I)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	166.		0.	I)	A)
T T AND C	37.		0.	I)	A)
REACTION AND CONTROL SYSTEM	0.		0.	I)	A)
POWER	93.		0.	I)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1300.		0.		

Table 6-12

AGENA SPACE TUG SEQUENCE OF EVENTS AND WEIGHTS FOR LOW-EARTH-ORBIT MISSION

(I_{sp} = 310 sec)

SUN SYNC (30 DAY MISSION) IMPROVED AGENA

SUN SYNCHRONOUS MISSION
INITIAL CONDITIONS 100NM CIR, 92.27 DEG INC EARTH ORBIT
TARGET CONDITIONS TARGET 1- 600NM CIR, 99.884 DEG INC TARGET 2- 400NM CIR, 98.262 DEG INC
FINAL CONDITIONS 100 NM CIRC 98.262 DEG INCL

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XSFER OPT INC SPLIT
RETURN FLIGHT PROFILE HOHMANN TRANSFER
STAY TIME AT TARGET 1.3 REV --- 29DAYS
PAYLOAD LENGTH 37.5 FT
PAYLOAD DELIVERED TO TARGET 10053. PAYLOAD DENSITY 3.089 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON 10053. PAYLOAD DENSITY 1.518 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 13534. RCS PROPELLANT 61.216
WET INERT WEIGHT 1596.

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	SPACE TUG DEPLOY (INCL=92.27)	0: 0: .0			35645.1		13534.1
			0.	RCS		.0	
		0: 0: .0			35645.1		13534.1
						11.0	
	XSFER ORBIT INJ (INCL=95.03)	0: 0:30.0			35634.1		13534.1
			1495.	MAIN		4956.4	
		0: 0:31.5			30677.9		8577.7
						47.0	
	MIDCOURSE + ATTITUDE CONTROL	0: 0:56.3			30630.9		8577.7
			7.	RCS		22.2	
		0: 0:57.4			30608.4		8577.7
						11.0	
	INJ 600NM CIR ORB (INC=99.884)	0: 1:21.4			30597.6		8577.7
			2145.	MAIN		5914.9	
		0: 1:23.2			24682.7		2662.8
						47.0	
	FLIGHT PERFORMANCE RESERVE	0: 1:23.2			24635.7		2662.8
TARGET 1			45.	MAIN		111.0	
		0: 1:23.2			24524.7		2551.8
						10064.0	
	XSFER ORBIT INJ (INCL = 99.04)	0: 3:40.7			14460.8		2551.8
			465.	MAIN		656.7	
		0: 3:40.9			13804.1		1895.1
						47.0	
	MIDCOURSE + ATTITUDE CONTROL	0: 4: 7.6			13757.1		1895.1
			5.	RCS		7.3	
		0: 4: 8.0			13749.8		1895.1
						11.0	
	INJ 400NM CIR ORB (INC=98.262)	0: 4:33.0			13738.8		1895.1
			456.	MAIN		612.6	
		0: 4:33.2			13126.2		1282.5
						47.0	
	FLIGHT PERFORMANCE RESERVE	0: 4:33.2			13079.2		1282.5
TARGET 2			9.	MAIN		11.8	
		0: 4:33.2			13067.4		1270.7
						11.0	
	XSFER ORBIT INJ (INCL= 98.262)	29: 4:33.2			13056.4		1270.7
			504.	MAIN		641.5	
		29: 4:33.4			12414.9		629.2

Table 6-12 (Cont)

						47.0	
	MIDCOURSE + ATTITUDE CONTROL	29: 4:57.3			12367.9		629.2
			27.	RCS		31.7	
		29: 4:59.0			12336.2		629.2
						11.0	
	INJ 100NM CIR ORB (INC=98.262)	29: 5:22.0			12325.2		629.2
			514.	MAIN		617.5	
		29: 5:22.2			11707.7		11.7
						47.0	
	FLIGHT PERFORMANCE RESERVE	29: 5:22.2			11660.7		11.7
FINAL			10.	MAIN		11.7	
		29: 5:22.2			11649.0		-.0

Table 6-12 (Cont)

SUN SYNC (30 DAY MISSION) IMPROVED AGENA

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	397.		0.	1)	4)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	567.		0.	1)	4)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	350.		0.	1)	4)
T T.AND C	37.		0.	1)	4)
REACTION AND CONTROL SYSTEM	0.		0.	1)	4)
POWER	166.		0.	1)	4)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1516.		0.		

6.3 PERFORMANCE GUIDELINES FOR EVOLUTIONARY AGENA SPACE TUG

The guidelines shown for the performance determination of the Agena space tug are similar in nature to those associated with the evolutionary Agena space tug.

6.3.1 Missions

The mission criteria for the improved Agena are as follows:

- Sizing Based on Synchronous-Equatorial Mission
- Performance Then Evaluated For

  Interplanetary Mars-Viking 1982
  Low Earth Sun-Synchronous Multiple Orbits 30-day Duration

6.3.2 Propulsion Characteristics

Besides the use of UDMH/HDA propellants and current Agena improvements giving an $I_{sp} = 310$ sec, the performance for an evolutionary Agena space tug using MMH/N_2O_4 propellants and the current Agena engine plus improvements, which in turn provides 322 sec of specific impulse was also calculated.

6.3.3 Vehicle Weights

In the case of the evolutionary Agena, the performance evaluation for maximum payload capability under the ignition weight constraint and for a synchronous equatorial mission and parametric stage weights as a function of propellant loading served to determine the optimum size stage. These parametric weights, shown in Fig. 6-2, were used in initial performance calculations to establish the basis for point design estimates used to determine the eventual payload capability. The variation in the parametric mass fraction (λ') values for the evolutionary Agena space tug produces a range of dry inert weights of from 1760 pounds to 2050 pounds, corresponding to propellant loads of 40,000 pounds and 60,000 pounds, respectively, for the HDA/UDMH propellant type. An equal range of propellant loadings for MMH/N_2O_4 means a dry inert weight range of from 1840 pounds to 2250 pounds, respectively.

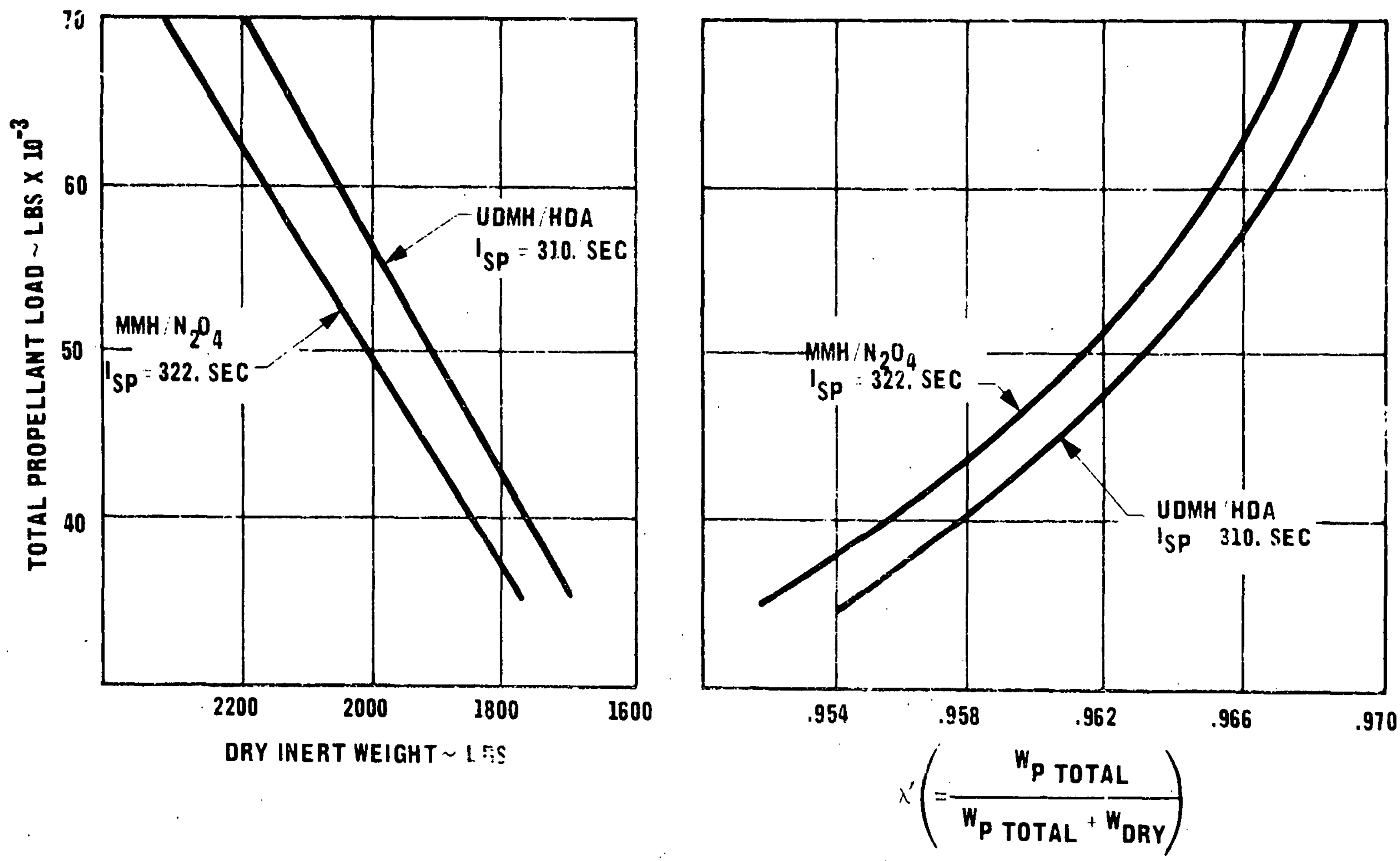


Fig. 6-2 Parametric Weight Relationships

6.3.4 Constraints

The structure constraint of 65,000 pounds due east space shuttle delivery capability was used and augmented with a 73,000-pound value to determine the performance and sizing impact of both space shuttle due east 100 nm circular orbit delivery capabilities.

6.3.5 Payload Capabilities

The parametric payload capability for the evolutionary Agena space tug is shown in Fig. 6-3. The range of propellant loadings, for HDA/UDMH, of 35,000 pounds to 70,000 pounds produces a maximum payload capability of 13,250 pounds at a synchronous equatorial mission for a fully loaded Agena of 48,800 pounds of propellant under the constraint of 64,200 pounds ignition weight. For a constraint of 71,000 pounds ignition weight, the Agena propellant loading goes to 53,000 pounds and a payload weight of 14,400 pounds can be orbited. The 64,200-pound ignition weight constraint assumes an 800-pound scar weight; the 71,000-pound constraint assumes a 2,000-pound scar weight. These values, when added to the constraints, correspond to the 65,000- and 73,000-pounds of space shuttle delivery capability. The estimated -3σ payload weight capability is based upon a flight performance reserve requirement equivalent to 1 percent of the mission ΔV. Figure 6-4 provides a cross-plot of the evolutionary Agena space tug impulse propellant weight as a function of payload weight for constant mission ΔV. The introduction of the 64,200-pound constraint and the subsequent payload curve under that constraint reflects the effect of offloading the stage from the value shown on the propellant weight scale.

Figures 6-5 and 6-6 provide similar data for the alternative propellant type evolutionary configuration. For MMH/N_2O_4 propellants, the parametric performance evaluation of stages ranging from 35,000 pounds to 70,000 pounds loading generates an optimum synchronous equatorial propellant weight of 46,500 pounds, giving a payload weight of approximately 13,600 pounds for a constrained ignition weight of 63,000 pounds. For a 71,000-pound limitation the sizing goes to 51,500 pounds of propellant and a payload of 15,000 pounds. Again, a 2,000-pound scar weight is assumed and the flight performance reserve is based upon 1 percent of a given mission's total ΔV.

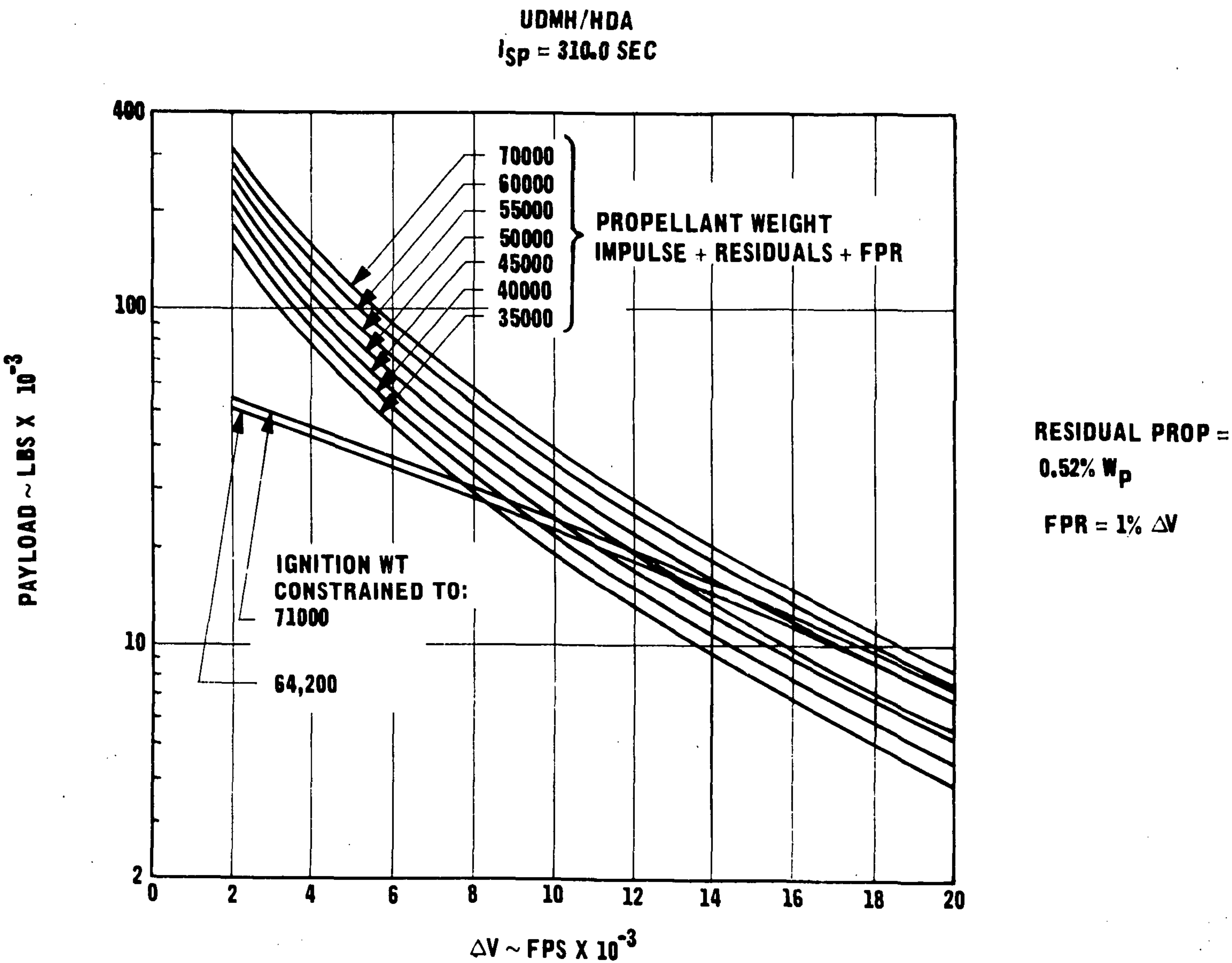


Fig. 6-3 Evolutionary Agena Performance – UDMH/HDA (I_{sp} = 310.0 sec)

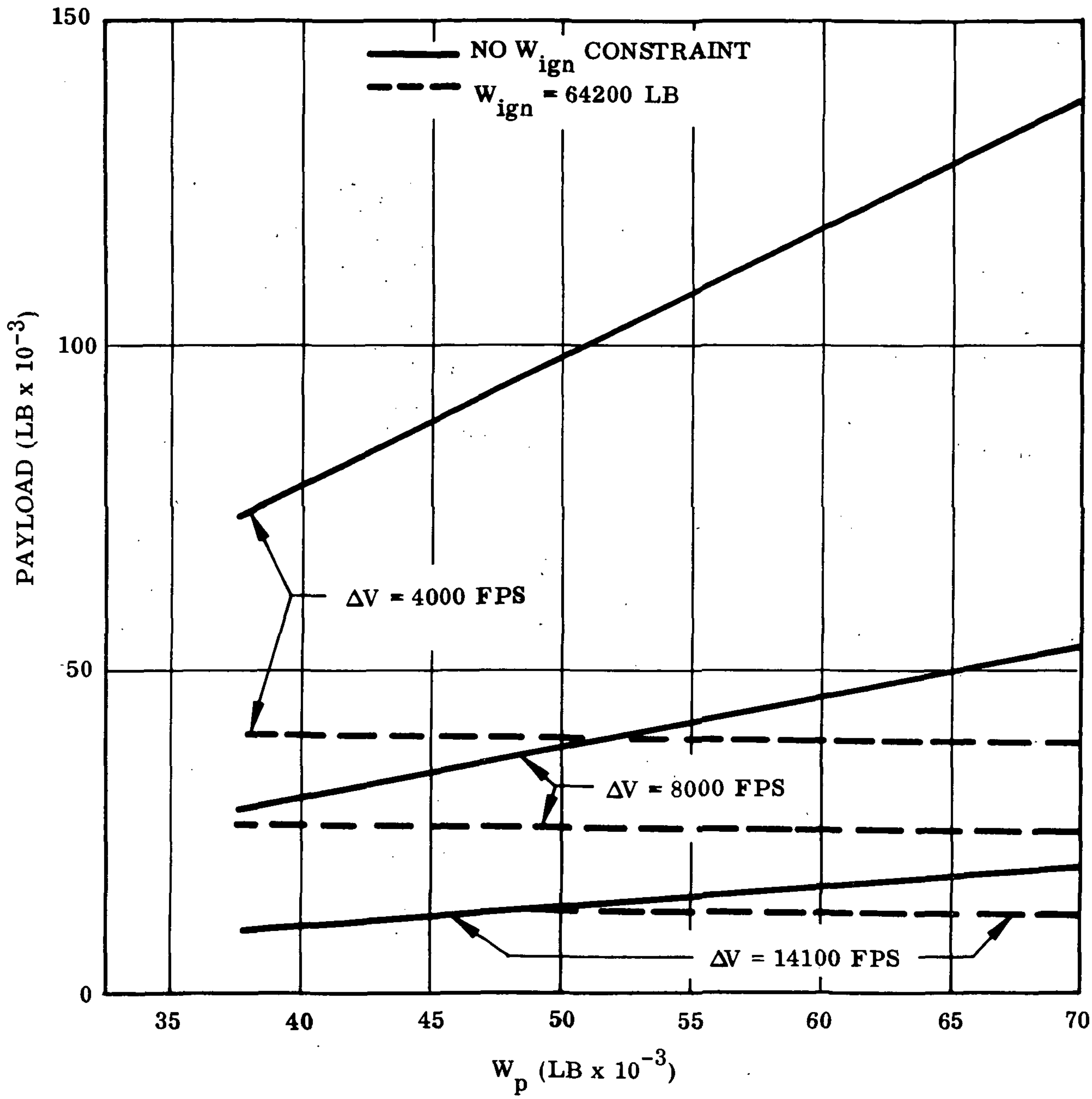


Fig. 6-4 Payload Versus Impulse Propellant – UDMH/HDA (I_{sp} = 310 sec)

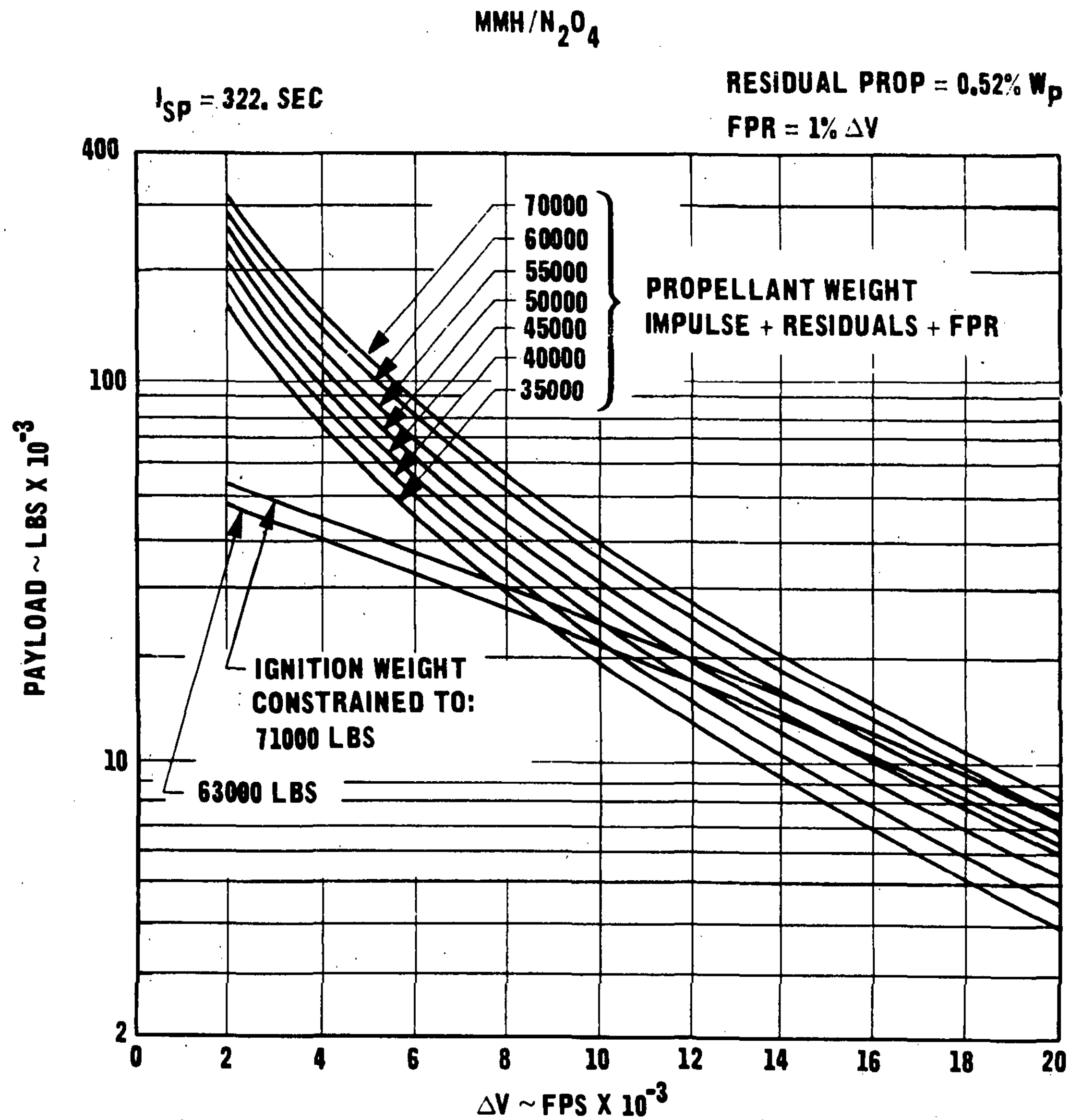


Fig. 6-5 Evolutionary Agena Performance – MMH/N_2O_4

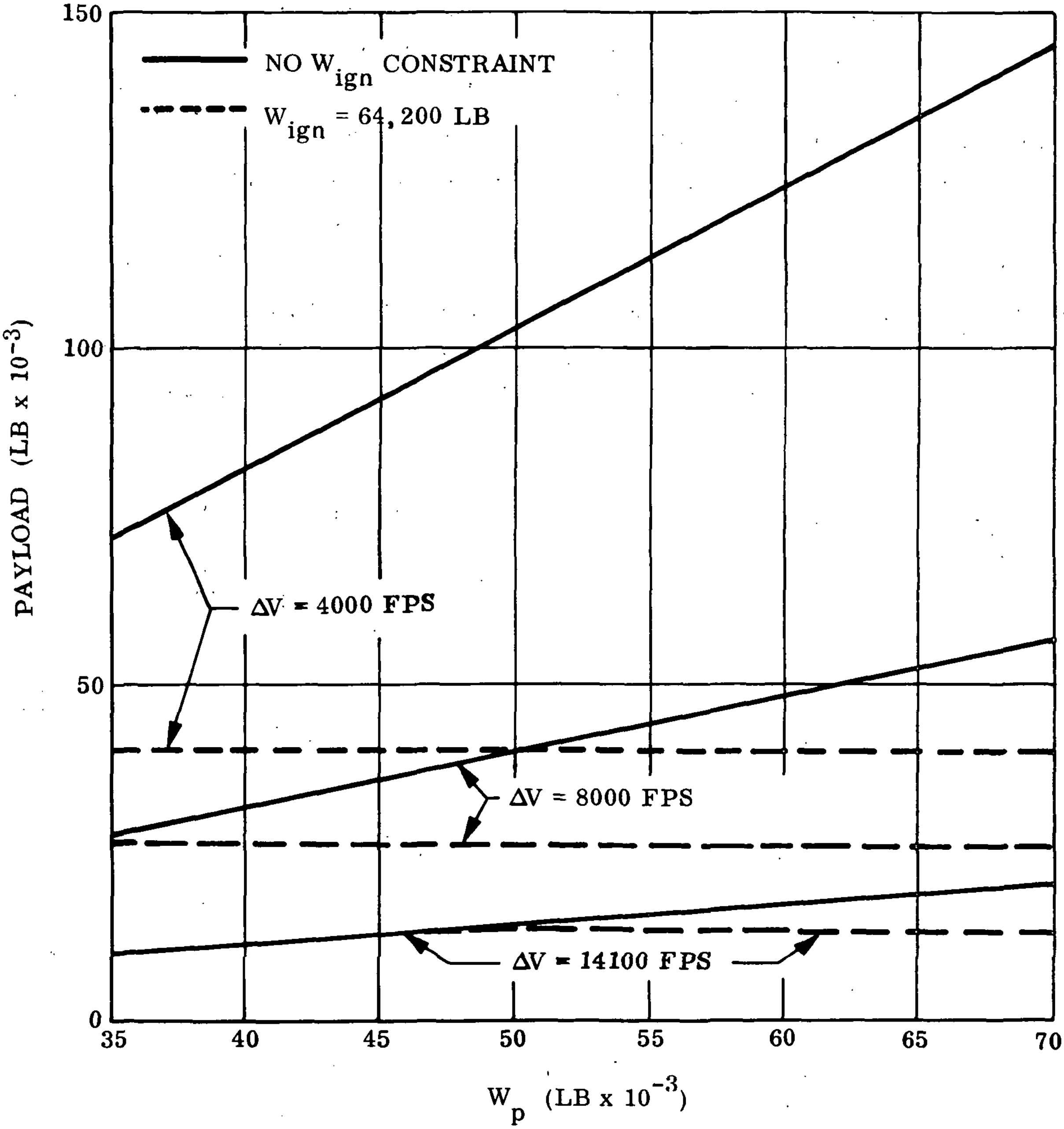


Fig. 6-6 Payload Versus Impulse Propellant – MMH/N_2O_4 (I_{sp} = 322 sec)

A summary of the payload capability for the evolutionary Agena space tug configurations given in Table 6-13 shows a five- to sixfold increase in maximum performance for the synchronous equatorial mission when compared to the Agena space tog configurations. The 1982 Viking interplanetary mission reflects an approximate four- to fivefold increase, but the low-earth, sun-synchronous orbit shows a loss in payload capability. This decrease in performance is due to the evolutionary Agena space tug propellant offloading required to satisfy the space shuttle delivery constraint for polar orbits. For this mission the increased inert weight of the evolutionary Agena space tug configurations associated with the unusable propellant loading generates a decrease in payload weight compared to the smaller Agena space tug. The absolute payload values shown for the synchronous equatorial mission differ from the values shown in the parametric propellant loading figures by virtue of the point design scar weights and actual mission sequence of events used in simulating the reference mission performance capability.

Table 6-13

EVOLUTIONARY AGENA SPACE TUG PAYLOAD CAPABILITY

	Payload Weight (lb)	
Mission	HDA/UDMH (I_{sp} = 310.0 sec)	N_2O_4/MMH (I_{sp} = 322.0 sec)
Synchronous-Equatorial	13,234	13,956
Interplanetary	16,512	17,276
Low Earth, Sun Sync Orbit*	9,504 (Each Orbit)	9,695 (Each Orbit)

*Agena space tug payload performance is constrained by space shuttle payload capability for polar orbit.

The preliminary definition of the components in the space shuttle cargo bay scar weight resulted in values ranging from 2000 pounds down to 800 pounds. The resultant impact on the evolutionary Agena space tug sizing over this range of weights is given in Fig. 6-7. Approximately 3/4 of the delta scar weight is attributed to a change in propellant loading, the remaining 1/4 to changing payload weight for the synchronous equatorial mission. Table 6-14 provides the data necessary to relate the evolutionary Agena space tug inert weights shown in Tables 6-15 through 6-24.

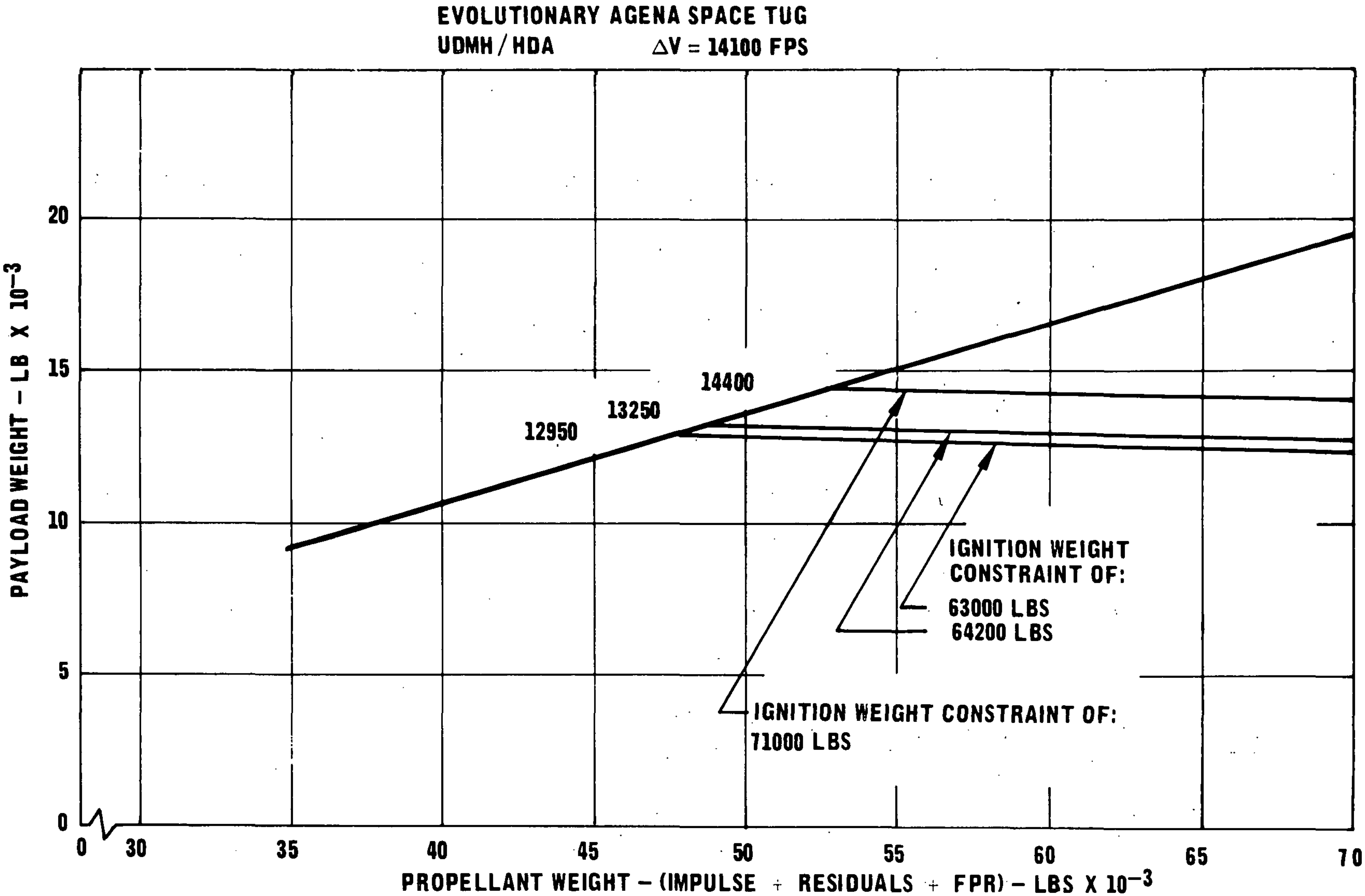


Fig. 6-7 Ignition Weight Sensitivity

Table 6-14

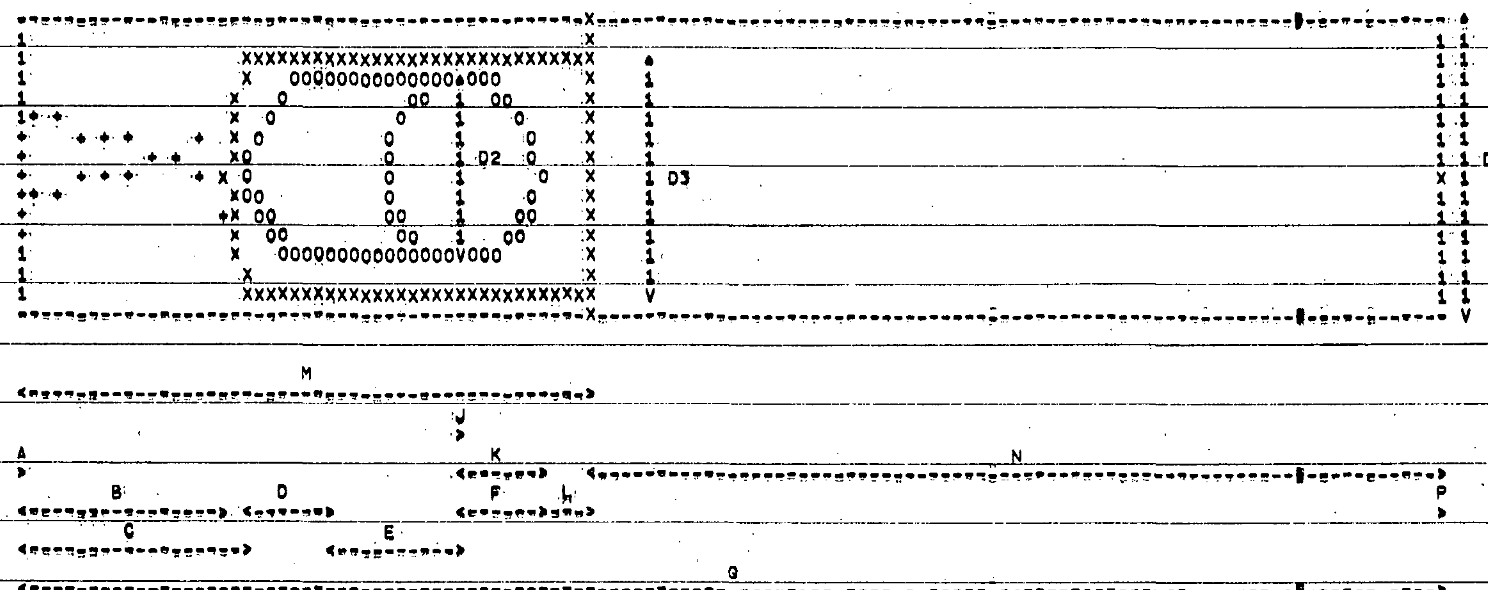
SUMMARY OF PERFORMANCE-PERTINENT WEIGHTS FOR EVOLUTIONARY AGENAS

	Synchronous-Equatorial Mission		Interplanetary Mission		Low-Earth-Orbit Mission	
	Agena I_{sp} = 310 sec	Agena I_{sp} = 322 sec	Agena I_{sp} = 310 sec	Agena I_{sp} = 322 sec	Agena I_{sp} = 310 sec	Agena I_{sp} = 322 sec
Dry Weight	1,854	1,963	1,741	1,850	2,030	2,139
Propellant Residuals	167	178	167	178	167	178
Pre-Flow	33	30	11	11	66	66
Post-Flow	180	162	60	54	360	324
Propellant Margin	216	220	224	225	133	131
Impulse Propellant	48,196	47,358	45,148	44,299	16,504	16,052
Helium Gas	10	10	10	10	10	10
N_2 Gas	31	31	31	31	81	81
Wet Ignition Weight	50,687	49,952	47,392	46,658	19,351	18,981
Pre- & Post-Flows	213	208	71	65	426	390
Impulse Propellant	48,196	47,358	45,148	44,299	16,504	16,052
Propellant Margin	216	220	224	225	133	131
N_2 Gas	8	9	8	9	63	63
Wet Weight at Burnout	2,053	2,173	1,940	2,060	2,225	2,345

Table 6-15

CANDIDATE EVOLUTIONARY STAGE CONFIGURATION

LTA UDMH/HDA



BULK HEAD ELLIPSE RATIO IS 1.4142

PAYLOAD LENGTH (FT)	TANK TYPE	TANK LENGTH (FT)	HEAD VOL. (FT3)	CYL. VOL. (FT3)	TOTAL VOL. (FT3)	ULLAGE VOL. (FT3)	NET TANK LIQUID (FT3)	STORED LIQUID (LB)	RESIDUAL LIQUID (LB)	TOTAL IMPULSE (LB)	SPECIFIC IMPULSE (SEC)
36.24	FUEL	6.5	291.8	.0	291.8	19.8	272.0	13356.8	45.7	13311.1	310.0
.00	OX	9.0	145.9	240.2	386.1	37.2	348.8	35435.6	121.3	35314.4	

GEOMETRY OF TANKS

DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q
IN FEET	.0	8.6	9.5	3.3	5.8	3.3	.0	.0	.0	.0	3.3	2.0	23.8	36.2	.0	60.0
IN INCHS	.0	103.2	114.2	39.2	69.1	39.2	.0	.0	.0	.0	39.2	23.4	285.1	434.9	.0	720.0

DIMENSION	D1	D2	D3	D4
IN FEET	9.2	9.2	10.0	15.0
IN INCHS	110.9	110.9	120.0	180.0

Table 6-15 (Cont)

ENGINE CHARACTERISTICS				
	PROPELLANT TYPE	MIXTURE RATIO (O/F)	OX DENSITY	FUEL DENSITY
MAIN ENGINE	UDMH/HDA	2.653	101.58 LBS/FT3	49.1 LBS/FT3
REACTION CONTROL SYSTEM	N2O4/UDMH			

MAIN SYSTEM	
DESIGNATION	8096 BELL ENGINE (MULTI-START)
SOURCE	BELL AEROSPACE CORPORATION
OPERATING CONDITIONS	
VACUUM THRUST	17620. LBS
VACUUM SPECIFIC IMPULSE	310.0 SEC
FLOW RATE	56.9 LB/SEC
EXPANSION RATIO	55/1
MINIMUM BIT IMPULSE	23750. LB-SEC

Table 6-16

EVOLUTIONARY STAGE PERFORMANCE SUMMARY (I_{sp} = 310 sec)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 2000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL, DEN, LB/FT3	P/L RET, DEN, LB/FT3
EXPENDABLE	267475,	48625,	216797,	0,	33,852	T000
FIXED IGN, WT,	65000,	11817,	51131,	0,	7,984	,000
REUSABLE/1	264827,	48625,	214149,	0,	33,439	T000
FIXED IGN, WT,	65000,	12298,	50649,	0,	7,909	,000
REUSABLE/2	144194,	48625,	93516,	93516,	14,602	14T602
FIXED IGN, WT,	65000,	21919,	41028,	41028,	6,406	6,406
REUSABLE/3	50678,	48625,	0,	166011,	,000	25T922
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	,779+03	,781+03	,000	,521+03	,521+03	,000	,117+04
ΔU1	-,985+06	-,975+06	,000	-,232+06	-,232+06	,000	-,145+06
ΔU2	-,113+05	-,113+05	,000	-,230+06	-,230+06	,000	-,717+06
ΔDV1	-,121+03	-,120+03	,000	-,284+02	-,284+02	,000	-,177+02
ΔDV2	-,113+01	-,140+01	,000	-,284+02	-,284+02	,000	-,888+02
ΔWI	-,100+01	-,229+01	,000	-,100+01	-,100+01	,000	-,178+01
ΔWP	,450+01	,450+01	,000	,197+01	,197+01	,000	,349+01
ΔR	,000	,276+06	-,964+06	,211+06	-,163+06	,166+06	-,129+06

ON ORBIT VELOCITY = 4000, FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL, DEN, LB/FT3	P/L RET, DEN, LB/FT3
EXPENDABLE	147109,	48625,	96431,	0,	15,057	T000
FIXED IGN, WT,	65000,	21485,	41462,	0,	6,474	,000
REUSABLE/1	143950,	48625,	93272,	0,	14,564	T000
FIXED IGN, WT,	65000,	22529,	40418,	0,	6,311	,000
REUSABLE/2	87409,	48625,	36731,	36731,	5,735	5T735
FIXED IGN, WT,	65000,	36159,	26788,	26788,	4,183	4,183
REUSABLE/3	50678,	48625,	0,	60593,	,000	9T461
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	,386+03	,390+03	,000	,239+03	,239+03	,000	,487+03
ΔU1	-,199+06	-,195+06	,000	-,467+05	-,467+05	,000	-,446+05
ΔU2	-,621+04	-,621+04	,000	-,462+05	-,462+05	,000	-,123+06
ΔDV1	-,299+02	-,292+02	,000	-,699+01	-,699+01	,000	-,669+01
ΔDV2	-,623+00	-,940+00	,000	-,699+01	-,699+01	,000	-,186+02
ΔWI	-,100+01	-,254+01	,000	-,100+01	-,100+01	,000	-,165+01
ΔWP	,203+01	,203+01	,000	,798+00	,798+00	,000	,132+01
ΔR	,000	,144+06	-,189+06	,891+05	-,579+05	,606+05	-,394+05

Table 6-16 (Cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 6000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	107520.	48625.	56842.	0.	8.876	1.000
FIXED IGN. WT.	65000.	29396.	33552.	0.	5.239	.000
REUSABLE/1	103690.	48625.	53012.	0.	8.278	1.000
FIXED IGN. WT.	65000.	31128.	31819.	0.	4.968	.000
REUSABLE/2	69173.	48625.	18495.	18495.	2.888	2.888
FIXED IGN. WT.	65000.	45692.	17255.	17255.	2.694	2.694
REUSABLE/3	50678.	48625.	0.	28404.	.000	4.435
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.253+03	.260+03	.000	.142+03	.142+03	.000	.261+03
ΔU1	-.713+05	-.688+05	.000	-.160+05	-.160+05	.000	-.180+05
ΔU2	-.454+04	-.454+04	.000	-.159+05	-.159+05	.000	-.361+05
ΔDV1	-.131+02	-.126+02	.000	-.293+01	-.293+01	.000	-.330+01
ΔDV2	-.455+00	-.840+00	.000	-.293+01	-.293+01	.000	-.668+01
ΔWI	-.100+01	-.287+01	.000	-.100+01	-.100+01	.000	-.154+01
ΔWP	.121+01	.121+01	.000	.423+00	.423+00	.000	.649+00
ΔR	.000	.989+05	-.642+05	.482+05	-.258+05	.284+05	-.152+05

ON ORBIT VELOCITY = 8000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	88118.	48625.	37440.	0.	5.846	1.000
FIXED IGN. WT.	65000.	35869.	27079.	0.	4.228	.000
REUSABLE/1	83459.	48625.	32776.	0.	5.118	1.000
FIXED IGN. WT.	65000.	38442.	24505.	0.	3.826	.000
REUSABLE/2	60695.	48625.	10017.	10017.	1.564	1.564
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	50678.	48625.	0.	14426.	.000	2.253
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	.185+03	.197+03	.000	.929+02	.929+02	.000	.154+03
ΔU1	-.321+05	-.304+05	.000	-.675+04	-.675+04	.000	-.812+04
ΔU2	-.372+04	-.372+04	.000	-.668+04	-.668+04	.000	-.131+05
ΔDV1	-.718+01	-.680+01	.000	-.151+01	-.151+01	.000	-.182+01
ΔDV2	-.373+00	-.841+00	.000	-.151+01	-.151+01	.000	-.297+01
ΔWI	-.100+01	-.327+01	.000	-.100+01	-.100+01	.000	-.144+01
ΔWP	.812+00	.812+00	.000	.248+00	.248+00	.000	.357+00
ΔR	.000	.745+05	-.266+05	.278+05	-.122+05	.144+05	-.635+04

LOCKHEED MISSILES & SPACE COMPANY

Table 6-16 (Cont)

P E R F O R M A N C E   S U M M A R Y

ON ORBIT VELOCITY = 10000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	76781.	48625.	26103.	0.	4.076	1000
FIXED IGN. WT.	65000.	41164.	21783.	0.	3.401	.000
REUSABLE/1	71095.	48625.	20417.	0.	3.188	1000
FIXED IGN. WT.	65000.	44766.	18182.	0.	2.839	.000
REUSABLE/2	56093.	48625.	5415.	5415.	.846	1846
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	50678.	48625.	0.	7369.	.000	11151
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ΔP/LD	REUSABLE/1 ΔP/LD	REUSABLE/1 ΔP/LR	REUSABLE/2 ΔP/LD	REUSABLE/2 ΔP/LR	REUSABLE/3 ΔP/LD	REUSABLE/3 ΔP/LR
ΔISP	.144+03	.162+03	.000	.634+02	.634+02	.000	.962+02
ΔU1	-.163+05	-.151+05	.000	-.316+04	-.316+04	.000	-.388+04
ΔU2	-.324+04	-.324+04	.000	-.313+04	-.313+04	.000	-.537+04
ΔDV1	-.446+01	-.413+01	.000	-.864+00	-.864+00	.000	-.106+01
ΔDV2	-.325+00	-.896+00	.000	-.864+00	-.864+00	.000	-.148+01
ΔWI	-.100+01	-.377+01	.000	-.100+01	-.100+01	.000	-.136+01
ΔWP	.579+00	.579+00	.000	.154+00	.154+00	.000	.209+00
ΔR	.000	.566+05	-.110+05	.159+05	-.574+04	.737+04	-.266+04

ON ORBIT VELOCITY = 12000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	69469.	48625.	18791.	0.	2.934	1000
FIXED IGN. WT.	65000.	45498.	17450.	0.	2.725	.000
REUSABLE/1	62529.	48625.	11851.	0.	1.850	1000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	53383.	48625.	2705.	2705.	.422	1422
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	50678.	48625.	0.	3505.	.000	1547
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ΔP/LD	REUSABLE/1 ΔP/LD	REUSABLE/1 ΔP/LR	REUSABLE/2 ΔP/LD	REUSABLE/2 ΔP/LR	REUSABLE/3 ΔP/LD	REUSABLE/3 ΔP/LR
ΔISP	.116+03	.143+03	.000	.442+02	.442+02	.000	.617+02
ΔU1	-.893+04	-.804+04	.000	-.157+04	-.157+04	.000	-.193+04
ΔU2	-.293+04	-.293+04	.000	-.155+04	-.155+04	.000	-.235+04
ΔDV1	-.299+01	-.269+01	.000	-.524+00	-.524+00	.000	-.645+00
ΔDV2	-.294+00	-.990+00	.000	-.524+00	-.524+00	.000	-.793+00
ΔWI	-.100+01	-.438+01	.000	-.100+01	-.100+01	.000	-.130+01
ΔWP	.429+00	.429+00	.000	.978-01	.978-01	.000	.127+00
ΔR	.000	.401+05	-.508+04	.835+04	-.247+04	.351+04	-.104+04

Table 6-16 (Cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 14100. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	64238,	48625,	13560,	0,	2,117	1000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/1	55680,	48625,	5002,	0,	,781	1000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/2	51646,	48625,	968,	968,	,151	1151
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/3	50678,	48625,	0,	1200,	,000	;187
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ▲P/LD	REUSABLE/1 ▲P/LD	REUSABLE/1 ▲P/LR	REUSABLE/2 ▲P/LD	REUSABLE/2 ▲P/LR	REUSABLE/3 ▲P/LD	REUSABLE/3 ▲P/LR
▲ISP	,941+02	,133+03	,000	,305+02	,305+02	,000	,392+02
▲U1	-,501+04	-,434+04	,000	-,780+03	-,780+03	,000	-,949+03
▲U2	-,271+04	-,271+04	,000	-,772+03	-,772+03	,000	-,103+04
▲DV1	-,207+01	-,179+01	,000	-,322+00	-,322+00	,000	-,392+00
▲DV2	-,272+00	-,113+01	,000	-,322+00	-,322+00	,000	-,430+00
▲WI	-,100+01	-,517+01	,000	-,100+01	-,100+01	,000	-,124+01
▲WP	,321+00	,321+00	,000	,621-01	,621-01	,000	,770-01
▲R	,000	,209+05	-,161+04	,312+04	-,749+03	,120+04	-,288+03

ON ORBIT VELOCITY = 16000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	60847,	48625,	10169,	0,	1,588	1000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/1	50500,	48625,	0,	0,	,000	1000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/2	50649,	48625,	0,	0,	,000	1000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/3	50678,	48625,	0,	0,	,000	1000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ▲P/LD	REUSABLE/1 ▲P/LD	REUSABLE/1 ▲P/LR	REUSABLE/2 ▲P/LD	REUSABLE/2 ▲P/LR	REUSABLE/3 ▲P/LD	REUSABLE/3 ▲P/LR
▲ISP	,792+02	,133+03	,000	,219+02	,219+02	,000	,262+02
▲U1	-,307+04	-,255+04	,000	-,423+03	-,423+03	,000	-,508+03
▲U2	-,257+04	-,257+04	,000	-,419+03	-,419+03	,000	-,501+03
▲DV1	-,153+01	-,127+01	,000	-,211+00	-,211+00	,000	-,253+00
▲DV2	-,258+00	-,130+01	,000	-,211+00	-,211+00	,000	-,253+00
▲WI	-,100+01	-,604+01	,000	-,100+01	-,100+01	,000	-,120+01
▲WP	,251+00	,251+00	,000	,416-01	,416-01	,000	,499-01
▲R	,000	-,899+03	,448+02	-,985+02	,195+02	-,354+02	,702+01

Table 6-17

EVOLUTIONARY STAGE SEQUENCE OF EVENTS AND WEIGHTS FOR SYNCHRONOUS-EQUATORIAL MISSION

(I_{sp} = 310 sec)

LTA UDMH/HDA SYN EQ

SYNCHRONOUS EQUATORIAL MISSION
INITIAL CONDITIONS 100NM CIRC, 28,3 DEG INC EARTH ORBIT
TARGET CONDITIONS 19330NM CIRC, 0 DEG INC EARTH ORBIT
FINAL CONDITIONS

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XFER OPT INCL SPLIT
RETURN FLIGHT PROFILE
STAY TIME AT TARGET
PAYLOAD LENGTH 36,2 FT
PAYLOAD DELIVERED TO TARGET 13234, PAYLOAD DENSITY ,033 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON 0, PAYLOAD DENSITY ,000 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 48412, RCS PROPELLANT 8,015
WET INERT WEIGHT 2053, MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	SPACE TUG DEPLOY (INCL=28,3)	01 0: ,0			63920,0		48412,5
			0,	RCS		,0	
		01 0: ,0			63920,0		48412,5
						11,0	
	PHASING ORBIT INJ (INCL=26,1)	01 0:30,0			63909,0		48412,5
			7932,	MAIN		35037,5	
		01 0:40,3			28871,5		13375,0
						60,0	
	ENGINE POST FLOW	01 0:40,3			28811,5		13375,0
			0,	MAIN		,0	
		01 0:40,3			28811,5		13375,0
						11,0	
	XFER ORBIT INJ (INCL=26,1)	01 9:48,3			28800,5		13375,0
			260,	MAIN		740,0	
		01 9:48,5			28060,6		12635,0
						60,0	
	MIDCOURSE + ATTITUDE CONTROL	0110:30,5			28000,6		12635,0
			3,	RCS		8,0	
		0110:30,9			27992,5		12635,0
						11,0	
	SYN EQ INJ (INCL=0,0)	0114:59,9			27981,5		12635,0
			5865,	MAIN		12418,8	
		0115: 3,6			15562,7		216,2
						60,0	
	FLIGHT PERFORMANCE RESERVES	0115: 3,6			15502,7		216,2
TARGET 1			140,	MAIN		216,2	
		0115: 3,6			15286,5		-,0

Table 6-17 (Cont)

LTA UDMH/HDA SYN EQ

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	421.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	875.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	208.		0.	1)	A)
T T AND C	170.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	180.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1854.		0.		

Table 6-18

EVOLUTIONARY STAGE SEQUENCE OF EVENTS AND WEIGHTS FOR INTERPLANETARY MISSION

LTA VDMH/HDA INTERPLANETARY

1982 VIKING MISSION
INITIAL CONDITICNS 100NM CIRC, 28,3 DEG INC EARTH ORBIT
TARGET CONDITICNS TRANS MARS INJECTION
FINAL CONDITICNS

COMMENTS
OUTBOUND FLIGHT PROFILE 10 DAY LAUNCH PERIOD
RETURN FLIGHT PROFILE
STAY TIME AT TARGET
PAYLOAD LENGTH 36,2 FT
PAYLOAD DELIVERED TO TARGET 16512, PAYLOAD DENSITY ,011 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON 0, PAYLOAD DENSITY ,000 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 45372, RCS PROPELLANT 8,015
WET INERT WEIGHT 1940,

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	TUG DEPLOY, FROM SPACE SHUTTLE	01 0: ,0			63903,3		45372,5
			1,	RCS		8,0	
		01 0: ,4			63895,3		45372,5
						11,0	
	TRANS-MARS INJECTION	01 0:30,4			63884,3		45372,5
			12750,	MAIN		45149,0	
		01 0:43,7			18735,3		223,5
						60,0	
	FLIGHT PERFORMANCE RESERVE	01 0:43,7			18675,3		223,5
TARGET 1			120,	MAIN		223,5	
		01 0:43,7			18451,8		*,0

LOCKHEED MISSILES & SPACE COMPANY

Table 6-18 (Cont)

LTA UDMH/HDA INTERPLANETARY

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	421.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	875.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	193.		0.	1)	A)
T T AND C	160.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	92.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1741.		0.		

Table 6-19

EVOLUTIONARY STAGE SEQUENCE OF EVENTS AND WEIGHTS FOR LOW-EARTH-ORBIT MISSION
(I_{sp} = 310 sec)

LTA UDMH/HDA SUN SYNC

SUN SYNCHRONOUS MISSION
INITIAL CONDITIONS 100NM CIRC, 90,0 DEG INC EARTH ORBIT
TARGET CONDITIONS TARGET 1= 600NM CIR, 99,884 DEG INC TARGET 2= 400NM CIR, 98,262 DEG INC
FINAL CONDITIONS 100 NM CIRC 98,262 DEG INCL

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XSFER OPT INC SPLIT
RETURN FLIGHT PROFILE HOHMANN TRANSFER
STAY TIME AT TARGET 1,3 REV --- 29DAYS
PAYLOAD LENGTH 36,2 FT
PAYLOAD DELIVERED TO TARGET 9504, PAYLOAD DENSITY 3,035 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON 9504, PAYLOAD DENSITY 1,484 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 16637, RCS PROPELLANT 62,894
WET INERT WEIGHT 2225,

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	SPACE TUG DEPLOY, (INCL= 90,0)	01 0: ,0			38358,8		16637,2
			0,	RCS		,0	
		01 0: ,0			38358,8		16637,2
						11,0	
	XSFER ORBIT INJ (INCL= 93,104)	01 0:30,0			38347,8		16637,2
			1633,	MAIN		5786,2	
		01 0:31,7			32561,6		10850,9
						60,0	
	MIDCOURSE + ATTITUDE CONTROL	01 0:56,5			32501,6		10850,9
			7,	RCS		23,6	
		01 0:57,8			32478,0		10850,9
						11,0	
	INJ 600NM CIR ORB (INC=99,884)	01 1:21,6			32467,0		10850,9
			2895,	MAIN		8168,7	
		01 1:24,2			24298,3		2682,3
						60,0	
	FLIGHT PERFORMANCE RESERVE	01 1:24,2			24238,3		2682,3
TARGET 1			45,	MAIN		109,2	
		01 1:24,2			24129,2		2573,1
						9514,9	
	XSFER ORBIT INJ (INCL = 99,04)	01 3:41,7			14614,3		2573,1
			465,	MAIN		663,1	
		01 3:41,9			13951,2		1910,0
						60,0	
	MIDCOURSE + ATTITUDE CONTROL	01 4: 8,6			13891,2		1910,0
			5,	RCS		7,3	
		01 4: 9,0			13883,9		1910,0
						11,0	
	INJ 400NM CIR ORB (INC=98,262)	01 4:34,0			13872,9		1910,0
			456,	MAIN		618,0	
		01 4:34,2			13254,8		1292,0
						60,0	
	FLIGHT PERFORMANCE RESERVE	01 4:34,2			13194,8		1292,0
TARGET 2			9,	MAIN		11,9	
		01 4:34,2			13182,9		1280,0
						11,0	
	XSFER ORBIT INJ (INCL= 98,262)	29 4:34,2			13171,9		1280,0
			504,	MAIN		646,5	
		29 4:34,4			12525,4		633,5

Table 6-19 (Cont)

						60,0	
	MIDCOURSE + ATTITUDE CONTROL	291 4:58,3			12465,4		633,5
			27,	RCS		32,0	
		291 4:60,0			12433,4		633,5
						11,0	
	INJ 100NM CIR ORB (INC=98,262)	291 5:23,0			12422,4		633,5
			514,	MAIN		621,8	
		291 5:23,2			11800,6		11,8
						60,0	
	FLIGHT PERFORMANCE RESERVE	291 5:23,2			11740,6		11,8
FINAL			10,	MAIN		11,8	
		291 5:23,2			11728,9		0,0

Table 6-19 (Cont)

LTA UDMH/HDA SUN SYNC

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	421.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	875.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	394.		0.	1)	A)
T T AND C	180.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	160.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	2030.		0.		

Table 6-20

EVOLUTIONATY STAGE CANDIDATE CONFIGURATION FOR N_2O_4/MMH PROPELLANTS (I_{sp} = 322 sec)

```
                              LTA      MMH/N204
 ----------------------------------------------X------------------------------------------------------------ A
 1                                             X                                                        1 1
 1                    XXXXXXXXXXXXXXXXXXXXXXXXXX  A                                                      1 1
 1                    X   000000000000000A000  X  1                                                      1 1
 1                    X 00          00   1   00  X  1                                                      1 1
 1+ +                 X 00          00   1    0  X  1                                                      1 1
 +    + + +        +  X 0           0    1    0  X  1                                                      1 1
 +          + +       X0            0    1 D2 0  X  1                                                      1 1 D4
 +    + + +        + X 0           0     1    0  X  1 D3                                                   X 1
 ++ +                 X0            0    1    0  X  1                                                      1 1
 +                   +X 0           0    1   00  X  1                                                      1 1
 +                    X 00          00   1  00C  X  1                                                      1 1
 1                    X  00000000000000V0000     X  1                                                      1 1
 1                    X                          X  1                                                      1 1
 1                    XXXXXXXXXXXXXXXXXXXXXXXXXXXX  V                                                      1 1
 ----------------------------------------------X------------------------------------------------------------ V

                            M
 <------------------------------------------------>
                                    J
                                    >
 A                                      K                                N
 >                                  <------->  <---------------------------------------------------------->
        B                D                  F      L                                                      P
 <--------------> <------->              <------->--->                                                    >
         C                       E
 <------------------>       <---------->
                                                            Q
 <---------------------------------------------------------------------------------------------------------->
```

BULK HEAD ELLIPSE RATIO IS 1,4142

PAYLOAD LENGTH (FT)	TANK TYPE	TANK LENGTH (FT)	HEAD VOL, (FT3)	CYL, VOL, (FT3)	TOTAL VOL, (FT3)	ULLAGE VOL, (FT3)	NET TANK LIQUID (FT3)	STORED LIQUID (LB)	RESIDUAL LIQUID (LB)	TOTAL IMPULSE (LB)	SPECIFIC IMPULSE (SEC)
36,45	FUEL	6,9	337,3	,0	337,3	25,9	311,4	17002,9	63,1	16939,7	322,0
,00	OX	8,7	168,7	217,5	386,1	40,6	345,5	30945,2	114,9	30830,3	

GEOMETRY OF TANKS

DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q
IN FEET	,0	8,6	9,5	3,4	5,2	3,4	,0	,0	,0	,0	3,4	2,0	23,6	36,4	,0	60,0
IN INCHS	,0	103,2	114,2	41,1	62,8	41,1	,0	,0	,0	,0	41,1	23,4	282,6	437,4	,0	720,0

DIMENSION	D1	D2	D3	D4
IN FEET	9,7	9,7	10,0	15,0
IN INCHS	116,3	116,3	120,0	180,0

Table 6-21

EVOLUTIONARY STAGE PERFORMANCE SUMMARY (I_{sp} = 322 sec)

P E R F O R M A N C E   S U M M A R Y

ON ORBIT VELOCITY = 2000, FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL, DEN, LB/FT3	P/L RET, DEN, LB/FT3
EXPENDABLE	271956,	47770,	222013,	0,	34,470	,000
FIXED IGN, WT,	65000,	11417,	51410,	0,	7,982	,000
REUSABLE/1	269175,	47770,	219232,	0,	34,038	,000
FIXED IGN, WT,	65000,	11906,	50921,	0,	7,906	,000
REUSABLE/2	146093,	47770,	96150,	96150,	14,928	14,928
FIXED IGN, WT,	65000,	21254,	41573,	41573,	6,455	6,455
REUSABLE/3	49943,	47770,	0,	171261,	,000	26,590
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ΔP/LD	REUSABLE/1 ΔP/LD	REUSABLE/1 ΔP/LR	REUSABLE/2 ΔP/LD	REUSABLE/2 ΔP/LR	REUSABLE/3 ΔP/LD	REUSABLE/3 ΔP/LR
ΔISP	,766+03	,767+03	,000	,514+03	,514+03	,000	,116+04
ΔU1	-,105+07	-,104+07	,000	-,248+06	-,248+06	,000	-,151+06
ΔU2	-,124+05	-,124+05	,000	-,245+06	-,245+06	,000	-,771+06
ΔDV1	-,123+03	-,122+03	,000	-,290+02	-,290+02	,000	-,177+02
ΔDV2	-,119+01	-,146+01	,000	-,290+02	-,290+02	,000	-,912+02
ΔWI	-,100+01	-,228+01	,000	-,100+01	-,100+01	,000	-,178+01
ΔWP	,469+01	,469+01	,000	,206+01	,206+01	,000	,367+01
ΔR	,000	,281+06	-,103+07	,216+06	-,169+06	,171+06	-,134+06

ON ORBIT VELOCITY = 4000, FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL, DEN, LB/FT3	P/L RET, DEN, LB/FT3
EXPENDABLE	149070,	47770,	99128,	0,	15,391	,000
FIXED IGN, WT,	65000,	20829,	41998,	0,	6,521	,000
REUSABLE/1	145776,	47770,	95834,	0,	14,879	,000
FIXED IGN, WT,	65000,	21885,	40942,	0,	6,357	,000
REUSABLE/2	88030,	47770,	38088,	38088,	5,914	5,914
FIXED IGN, WT,	65000,	35273,	27555,	27555,	4,278	4,278
REUSABLE/3	49943,	47770,	0,	63209,	,000	9,814
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ΔP/LD	REUSABLE/1 ΔP/LD	REUSABLE/1 ΔP/LR	REUSABLE/2 ΔP/LD	REUSABLE/2 ΔP/LR	REUSABLE/3 ΔP/LD	REUSABLE/3 ΔP/LR
ΔISP	,379+03	,383+03	,000	,237+03	,237+03	,000	,486+03
ΔU1	-,215+06	-,210+06	,000	-,504+05	-,504+05	,000	-,475+05
ΔU2	-,678+04	-,678+04	,000	-,499+05	-,499+05	,000	-,135+06
ΔDV1	-,305+02	-,299+02	,000	-,717+01	-,717+01	,000	-,675+01
ΔDV2	-,655+00	-,973+00	,000	-,717+01	-,717+01	,000	-,193+02
ΔWI	-,100+01	-,252+01	,000	-,100+01	-,100+01	,000	-,166+01
ΔWP	,212+01	,212+01	,000	,843+00	,843+00	,000	,140+01
ΔR	,000	,145+06	-,203+06	,918+05	-,605+05	,632+05	-,417+05

Table 6-21 (Cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 6000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	108613.	47770.	58671.	0.	9.109	.000
FIXED IGN. WT.	65000.	28588.	34239.	0.	5.316	.000
REUSABLE/1	104649.	47770.	54707.	0.	8.494	.000
FIXED IGN. WT.	65000.	30332.	32496.	0.	5.045	.000
REUSABLE/2	69311.	47770.	19368.	19368.	3.007	3.007
FIXED IGN. WT.	65000.	44799.	18029.	18029.	2.799	2.799
REUSABLE/3	49943.	47770.	0.	29984.	.000	4.655
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ΔP/LD	REUSABLE/1 ΔP/LD	REUSABLE/1 ΔP/LR	REUSABLE/2 ΔP/LD	REUSABLE/2 ΔP/LR	REUSABLE/3 ΔP/LD	REUSABLE/3 ΔP/LR
ΔISP	.249+03	.256+03	.000	.141+03	.141+03	.000	.262+03
ΔU1	-.775+05	-.747+05	.000	-.175+05	-.175+05	.000	-.195+05
ΔU2	-.494+04	-.494+04	.000	-.173+05	-.173+05	.000	-.401+05
ΔDV1	-.134+02	-.129+02	.000	-.302+01	-.302+01	.000	-.337+01
ΔDV2	-.477+00	-.860+00	.000	-.302+01	-.302+01	.000	-.698+01
ΔWI	-.100+01	-.282+01	.000	-.100+01	-.100+01	.000	-.155+01
ΔWP	.127+01	.127+01	.000	.451+00	.451+00	.000	.698+00
ΔR	.000	.998+05	-.697+05	.500+05	-.274+05	.300+05	-.164+05

ON ORBIT VELOCITY = 8000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN, LB/FT3	P/L RET. DEN, LB/FT3
EXPENDABLE	88756.	47770.	38814.	0.	6.026	.000
FIXED IGN. WT.	65000.	34984.	27843.	0.	4.323	.000
REUSABLE/1	83967.	47770.	34024.	0.	5.283	.000
FIXED IGN. WT.	65000.	37562.	25266.	0.	3.923	.000
REUSABLE/2	60560.	47770.	10617.	10617.	1.648	1.648
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	49943.	47770.	0.	15433.	.000	2.396
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ΔP/LD	REUSABLE/1 ΔP/LD	REUSABLE/1 ΔP/LR	REUSABLE/2 ΔP/LD	REUSABLE/2 ΔP/LR	REUSABLE/3 ΔP/LD	REUSABLE/3 ΔP/LR
ΔISP	.183+03	.194+03	.000	.931+02	.931+02	.000	.157+03
ΔU1	-.352+05	-.333+05	.000	-.749+04	-.749+04	.000	-.898+04
ΔU2	-.404+04	-.404+04	.000	-.742+04	-.742+04	.000	-.148+05
ΔDV1	-.735+01	-.696+01	.000	-.157+01	-.157+01	.000	-.188+01
ΔDV2	-.390+00	-.852+00	.000	-.157+01	-.157+01	.000	-.313+01
ΔWI	-.100+01	-.320+01	.000	-.100+01	-.100+01	.000	-.145+01
ΔWP	.858+00	.858+00	.000	.268+00	.268+00	.000	.389+00
ΔR	.000	.750+05	-.292+05	.292+05	-.133+05	.154+05	-.700+04

P E R F O R M A N C E   S U M M A R Y

ON ORBIT VELOCITY = 10000. FPS

MISSION MODE	IGNITION WT. LB	PROPELLANT WT. LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN. LB/FT3	P/L RET. DEN. LB/FT3
EXPENDABLE	77132.	47770.	27189.	0.	4.221	.000
FIXED IGN. WT.	65000.	40256.	22571.	0.	3.504	.000
REUSABLE/1	71335.	47770.	21392.	0.	3.321	.000
FIXED IGN. WT.	65000.	43847.	18981.	0.	2.947	.000
REUSABLE/2	55775.	47770.	5832.	5832.	.905	.905
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	49943.	47770.	0.	8018.	.000	1.245
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ΔP/LD	REUSABLE/1 ΔP/LD	REUSABLE/1 ΔP/LR	REUSABLE/2 ΔP/LD	REUSABLE/2 ΔP/LR	REUSABLE/3 ΔP/LD	REUSABLE/3 ΔP/LR
ΔISP	.142+03	.160+03	.000	.640+02	.640+02	.000	.986+02
ΔU1	-.180+05	-.167+05	.000	-.356+04	-.356+04	.000	-.438+04
ΔU2	-.351+04	-.351+04	.000	-.352+04	-.352+04	.000	-.617+04
ΔDV1	-.458+01	-.423+01	.000	-.903+00	-.903+00	.000	-.111+01
ΔDV2	-.339+00	-.899+00	.000	-.903+00	-.903+00	.000	-.158+01
ΔWI	-.100+01	-.367+01	.000	-.100+01	-.100+01	.000	-.137+01
ΔWP	.615+00	.615+00	.000	.168+00	.168+00	.000	.230+00
ΔR	.000	.571+05	-.131+05	.170+05	-.636+04	.802+04	-.301+04

ON ORBIT VELOCITY = 12000. FPS

MISSION MODE	IGNITION WT. LB	PROPELLANT WT. LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL. DEN. LB/FT3	P/L RET. DEN. LB/FT3
EXPENDABLE	69616.	47770.	19673.	0.	3.054	.000
FIXED IGN. WT.	65000.	44603.	18225.	0.	2.830	.000
REUSABLE/1	62594.	47770.	12652.	0.	1.964	.000
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/2	52932.	47770.	2990.	2990.	.464	.464
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000
REUSABLE/3	49943.	47770.	0.	3915.	.000	.608
FIXED IGN. WT.	65000.	0.	0.	0.	.000	.000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE ΔP/LD	REUSABLE/1 ΔP/LD	REUSABLE/1 ΔP/LR	REUSABLE/2 ΔP/LD	REUSABLE/2 ΔP/LR	REUSABLE/3 ΔP/LD	REUSABLE/3 ΔP/LR
ΔISP	.115+03	.140+03	.000	.451+02	.451+02	.000	.638+02
ΔU1	-.999+04	-.898+04	.000	-.180+04	-.180+04	.000	-.222+04
ΔU2	-.317+04	-.317+04	.000	-.178+04	-.178+04	.000	-.274+04
ΔDV1	-.307+01	-.276+01	.000	-.552+00	-.552+00	.000	-.683+00
ΔDV2	-.306+00	-.984+00	.000	-.552+00	-.552+00	.000	-.853+00
ΔWI	-.100+01	-.423+01	.000	-.100+01	-.100+01	.000	-.131+01
ΔWP	.457+00	.457+00	.000	.108+00	.108+00	.000	.142+00
ΔR	.000	.409+05	-.579+04	.913+04	-.283+04	.391+04	-.121+04

Table 6-21 (Cont)

PERFORMANCE SUMMARY

ON ORBIT VELOCITY = 14100. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL, DEN, LB/FT3	P/L RET, DEN, LB/FT3
EXPENDABLE	64224,	47770,	14281,	0,	2,217	.000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/1	55633,	47770,	5691,	0,	,884	.000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/2	51091,	47770,	1149,	1149,	,178	.178
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/3	49943,	47770,	0,	1439,	,000	.223
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	,936+02	,130+03	,000	,315+02	,315+02	,000	,411+02
ΔU1	-,567+04	-,491+04	,000	-,910+03	-,910+03	,000	-,111+04
ΔU2	-,292+04	-,292+04	,000	-,901+03	-,901+03	,000	-,123+04
ΔDV1	-,214+01	-,185+01	,000	-,343+00	-,343+00	,000	-,420+00
ΔDV2	-,282+00	-,111+01	,000	-,343+00	-,343+00	,000	-,467+00
ΔWI	-,100+01	-,495+01	,000	-,100+01	-,100+01	,000	-,125+01
ΔWP	,344+00	,344+00	,000	,695-01	,695-01	,000	,871-01
ΔR	,000	,225+05	-,196+04	,367+04	-,927+03	,144+04	-,364+03

ON ORBIT VELOCITY = 16000. FPS

MISSION MODE	IGNITION WT, LB	PROPELLANT WT, LB	P/L DELIVERED LB	P/L RETURNED LB	P/L DEL, DEN, LB/FT3	P/L RET, DEN, LB/FT3
EXPENDABLE	60718,	47770,	10775,	0,	1,673	.000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/1	50409,	47770,	461,	0,	,072	.000
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/2	50023,	47770,	80,	80,	,012	.012
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000
REUSABLE/3	49943,	47770,	0,	97,	,000	.015
FIXED IGN, WT,	65000,	0,	0,	0,	,000	,000

MISSION, DISIGN, AND PERFORMANCE SENSITIVITIES

	EXPENDABLE	REUSABLE/1		REUSABLE/2		REUSABLE/3	
	ΔP/LD	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR	ΔP/LD	ΔP/LR
ΔISP	,790+02	,129+03	,000	,228+02	,228+02	,000	,277+02
ΔU1	-,351+04	-,291+04	,000	-,503+03	-,503+03	,000	-,608+03
ΔU2	-,276+04	-,276+04	,000	-,498+03	-,498+03	,000	-,608+03
ΔDV1	-,159+01	-,132+01	,000	-,228+00	-,228+00	,000	-,275+00
ΔDV2	-,267+00	-,126+01	,000	-,228+00	-,228+00	,000	-,278+00
ΔWI	-,100+01	-,575+01	,000	-,100+01	-,100+01	,000	-,121+01
ΔWP	,271+00	,271+00	,000	,472-01	,472-01	,000	,571-01
ΔR	,000	,219+04	-,125+03	,265+03	-,559+02	,972+02	-,205+02

Table 6-22

EVOLUTIONARY STAGE SEQUENCE OF EVENTS AND WEIGHTS FOR SYNCHRONOUS-EQUATORIAL MISSION (I_{sp} = 322 sec)

LTA   MMH/N204   SYN EQ

SYNCHRONOUS EQUATORIAL MISSION
INITIAL CONDITIONS 100NM CIRC. 28.3 DEG INC EARTH ORBIT
TARGET CONDITIONS 19330NM CIRC. 0 DEG INC EARTH ORBIT
FINAL CONDITIONS

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XFER OPT INCL SPLIT
RETURN FLIGHT PROFILE
STAY TIME AT TARGET
PAYLOAD LENGTH 36.4 FT
PAYLOAD DELIVERED TO TARGET 13956. PAYLOAD DENSITY .030 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON 0. PAYLOAD DENSITY .000 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 47578. RCS PROPELLANT 8.266
WET INERT WEIGHT 2173.

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	SPACE TUG DEPLOY (INCL=28.3)	0: 0: .0			63906.7		47578.1
			0.	RCS		.0	
		0: 0: .0			63906.7		47578.1
						10.0	
	PHASING ORBIT INJ (INCL=26.1)	0: 0:30.0			63896.7		47578.1
			7932.	MAIN		34166.9	
		0: 0:41.2			29729.8		13411.2
						54.0	
	ENGINE POST FLOW	0: 0:41.2			29675.8		13411.2
			0.	MAIN		.0	
		0: 0:41.2			29675.8		13411.2
						10.0	
	XFER ORBIT INJ (INCL=26.1)	0: 9:49.2			29665.8		13411.2
			260.	MAIN		734.3	
		0: 9:49.5			28931.4		12676.8
						54.0	
	MIDCOURSE + ATTITUDE CONTROL	0:10:31.5			28877.4		12676.8
			3.	RCS		8.3	
		0:10:31.9			28869.2		12676.8
						10.0	
	SYN EQ INJ (INCL=0.0)	0:15: .9			28859.2		12676.8
			5865.	MAIN		12457.3	
		0:15: 5.0			16401.9		219.6
						54.0	
	FLIGHT PERFORMANCE RESERVES	0:15: 5.0			16347.9		219.6
TARGET 1			140.	MAIN		219.6	
		0:15: 5.1			16128.3		-.0

Table 6-22 (Cont)

LTA MMH/N2O4 SYN EQ

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	421.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START/COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	974.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	208.		0.	1)	A)
T T AND C	180.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	180.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	1963.		0.		

Table 6-23

EVOLUTIONARY STAGE SEQUENCE OF EVENTS AND WEIGHTS FOR INTERPLANETARY MISSION
(I_{sp} = 322 sec)

LTA MMH/N2O4 INTERPLANETARY

1982 VIKING MISSION
INITIAL CONDITIONS 100NM CIRC. 28.3 DEG INC EARTH ORBIT
TARGET CONDITIONS TRANS MARS INJECTION
FINAL CONDITIONS

COMMENTS
OUTBOUND FLIGHT PROFILE 10 DAY LAUNCH PERIOD
RETURN FLIGHT PROFILE
STAY TIME AT TARGET

PAYLOAD LENGTH	36.4 FT			
PAYLOAD DELIVERED TO TARGET	17276.	PAYLOAD DENSITY	.010 LB/FT3	BASED ON D4
PAYLOAD RETURNED TO FINAL CON	0.	PAYLOAD DENSITY	.000 LB/FT3	BASED ON D4
IMPULSE PROPELLANT	44524.	RCS PROPELLANT	8.019	
WET INERT WEIGHT	2060.			

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	TUG DEPLOY, FROM SPACE SHUTTLE	0: 0: .0			63933.2		44524.1
			1.	RCS		8.0	
		0: 0: .4			63925.1		44524.1
						11.0	
	TRANS-MARS INJECTION	0: 0:30.4			63914.1		44524.1
			12250.	MAIN		44298.7	
		0: 0:45.0			19615.5		225.4
						54.0	
	FLIGHT PERFORMANCE RESERVE	0: 0:45.0			19561.5		225.4
TARGET 1			120.	MAIN		225.4	
		0: 0:45.1			19336.1		0.0

Table 6-23 (Cont)

LTA MMH/N2O4 INTERPLANETARY

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION		WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM		421.		0.	1)	A)
	ENGINE		0.			
	PRESSURIZATION COMPONENTS		0.			
	START COMPONENTS (NUMBER OF STARTS= 0)		0.			
	VALVES AND PLUMBING		0.			
STRUCTURES		974.		0.	1)	A)
	TANKS		0.			
	FORWARD INTERSTAGE, DOORS, RACKS		0.			
	AFT RACK AND MISCELLANOUS		0.			
	INSULATION		0.			
GUIDANCE AND CONTROL		193.		0.	1)	A)
T T AND C		170.		0.	1)	A)
REACTION AND CONTROL SYSTEM		0.		0.	1)	A)
POWER		92.		0.	1)	A)
	BATTERIES		0.			
	WIRE HARNESSES		0.			
	J-BOXES AND MISCELLANEOUS		0.			
TOTAL		1850.		0.		

Table 6-24

EVOLUTIONARY STAGE SEQUENCE OF EVENTS AND WEIGHTS FOR LOW-EARTH-ORBIT MISSION
(I_{sp} = 322 sec)

LTA MMH/N204 SUN SYNC

SUN SYNCHRONOUS MISSION
INITIAL CONDITIONS 100NM CIRC, 90.0 DEG INC EARTH ORBIT

TARGET CONDITIONS TARGET 1- 600NM CIR, 99.884 DEG INC TARGET 2- 400NM CIR, 98.262 DEG INC
FINAL CONDITIONS 100 NM CIRC 98.262 DEG INCL

COMMENTS
OUTBOUND FLIGHT PROFILE HOHMANN XSFER OPT INC SPLIT
RETURN FLIGHT PROFILE HOHMANN TRANSFER
STAY TIME AT TARGET 1.3 REV =-- 29DAYS
PAYLOAD LENGTH 36.4 FT
PAYLOAD DELIVERED TO TARGET 9695. PAYLOAD DENSITY 3.069 LB/FT3 BASED ON D4
PAYLOAD RETURNED TO FINAL CON. 9695. PAYLOAD DENSITY 1.505 LB/FT3 BASED ON D4
IMPULSE PROPELLANT 16183. RCS PROPELLANT 63.939
WET INERT WEIGHT 2345.

MISSION SEQUENCE

CONDITIONS	EVENT	TIME DY:HR:MIN	DELTA V FPS	ENGINE TYPE	WEIGHT LBS	DELTA WT LBS	IMP PROP REM LBS
INITIAL	SPACE TUG DEPLOY, (INCL= 90.0)	0: 0: .0			38359.6		16183.1
			0.	RCS		.0	
		0: 0: .0			38359.6		16183.1
						9.0	
	XSFER ORBIT INJ (INCL= 93.104)	0: 0:30.0			38350.6		16183.1
			1633.	MAIN		5588.5	
		0: 0:31.8			32762.1		10594.6
						54.0	
	MIDCOURSE + ATTITUDE CONTROL	0: 0:56.6			32708.1		10594.6
			7.	RCS		23.7	
		0: 0:57.9			32684.4		10594.6
						9.0	
	INJ 600NM CIR ORB (INC=99.884)	0: 1:21.9			32675.4		10594.6
			2895.	MAIN		7957.2	
		0: 1:24.5			24718.2		2637.4
						54.0	
	FLIGHT PERFORMANCE RESERVE	0: 1:24.5			24664.2		2637.4
TARGET 1			45.	MAIN		107.0	
		0: 1:24.6			24557.2		2530.5
						9703.7	
	XSFER ORBIT INJ (INCL = 99.04)	0: 3:42.1			14853.5		2530.5
			465.	MAIN		649.7	
		0: 3:42.3			14203.8		1880.8
						54.0	
	MIDCOURSE + ATTITUDE CONTROL	0: 4: 9.0			14149.8		1880.8
			5.	RCS		7.5	
		0: 4: 9.4			14142.3		1880.8
						9.0	
	INJ 400NM CIR ORB (INC=98.262)	0: 4:34.4			14133.3		1880.8
			456.	MAIN		607.0	
		0: 4:34.6			13526.3		1273.8
						54.0	
	FLIGHT PERFORMANCE RESERVE	0: 4:34.6			13472.3		1273.8
TARGET 2			9.	MAIN		11.7	
		0: 4:34.6			13460.6		1262.1
						9.0	
	XSFER ORBIT INJ (INCL= 98.262)	29: 4:34.6			13451.6		1262.1
			504.	MAIN		636.6	
		29: 4:34.8			12815.0		625.5

Table 6-24 (Cont)

						54.0	
	MIDCOURSE + ATTITUDE CONTROL	29: 4:58.7			12761.0		625.5
			27.	RCS		32.7	
		29: 5: .5			12728.3		625.5
						9.0	
	INJ 100NM CIR ORB (INC=98.262)	29: 5:23.5			12719.3		625.5
			514.	MAIN		613.8	
		29: 5:23.7			12105.5		11.6
						54.0	
	FLIGHT PERFORMANCE RESERVE	29: 5:23.7			12051.5		11.6
FINAL			10.	MAIN		11.6	
		29: 5:23.7			12039.8		".0

Table 6-24 (Cont)

LTA MMH/N204 SUN SYNC

SPACE TUG WEIGHT AND COST SUMMARY

SYSTEM DEFINITION	WEIGHT LB		COST M$	SOURCE WEIGHT	SOURCE COST
PROPULSION SYSTEM	421.		0.	1)	A)
ENGINE		0.			
PRESSURIZATION COMPONENTS		0.			
START COMPONENTS (NUMBER OF STARTS= 0)		0.			
VALVES AND PLUMBING		0.			
STRUCTURES	974.		0.	1)	A)
TANKS		0.			
FORWARD INTERSTAGE, DOORS, RACKS		0.			
AFT RACK AND MISCELLANOUS		0.			
INSULATION		0.			
GUIDANCE AND CONTROL	394.		0.	1)	A)
T T AND C	190.		0.	1)	A)
REACTION AND CONTROL SYSTEM	0.		0.	1)	A)
POWER	160.		0.	1)	A)
BATTERIES		0.			
WIRE HARNESSES		0.			
J-BOXES AND MISCELLANEOUS		0.			
TOTAL	2139.		0.		

6.4 PARAMETRIC PERFORMANCE CAPABILITY

For preliminary planning purposes, Fig. 6-8 provides curves of ΔV versus payload capability for the four Agena space tug point designs which serve to illustrate the areas of potential mission compatibility. Payload weights for ignition weights equal to or less than 65,000 pounds are shown, along with capability reflecting no ignition weight constraint. The larger ignition weight cases could be used to reflect capability where the Agena space tug and the payload are transported to orbit in separate space shuttle flights.

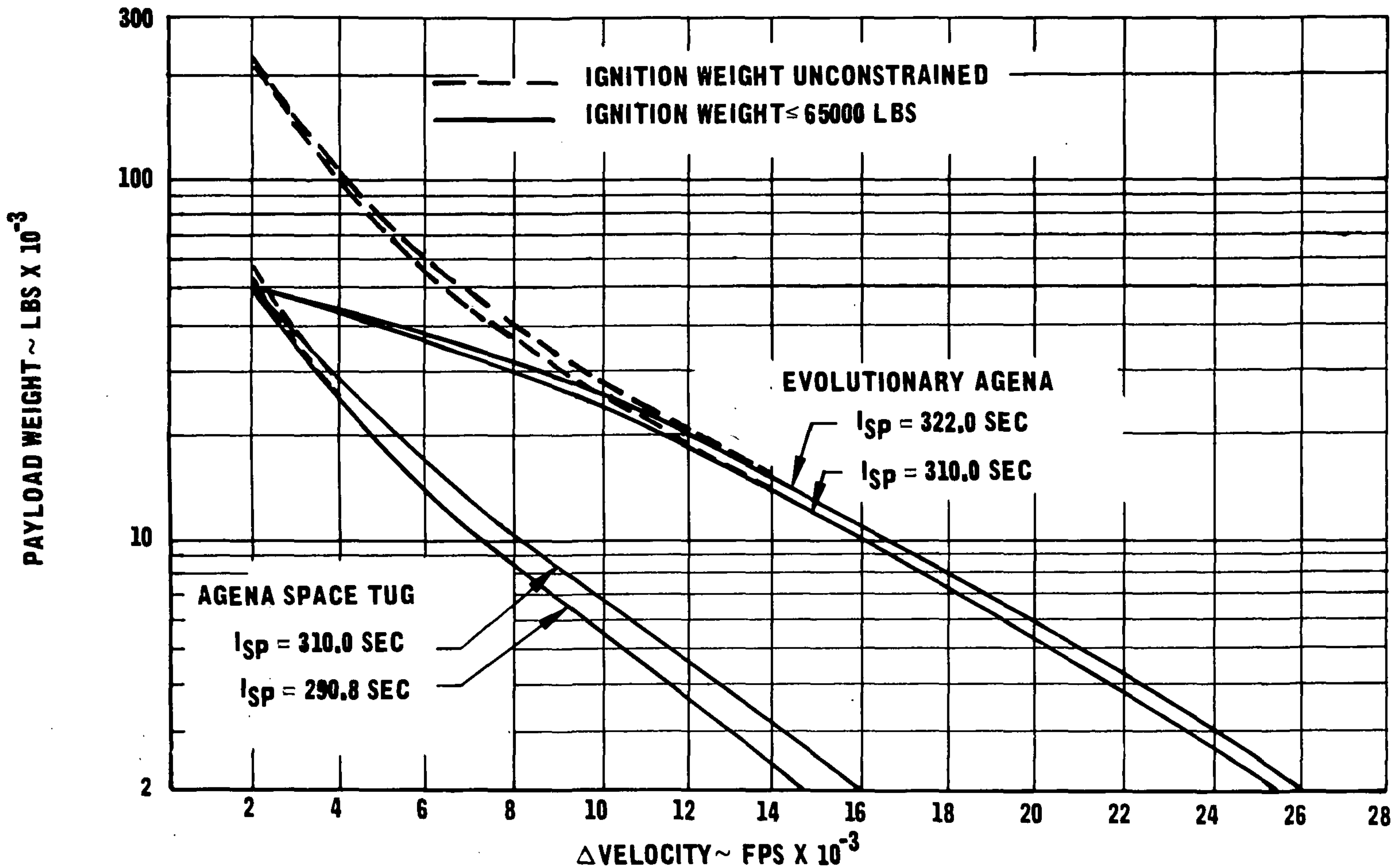


Fig. 6-8 Agena Space Tug Performance Capability

Section 7

AGENA TUG SAFETY ASSESSMENT

Section 7
AGENA TUG SAFETY ASSESSMENT

It is recognized that in the Agena tug development maximum consideration must be given to shuttle crew and passenger safety. Adequate safety can be assured only by selecting those design approaches and operational procedures that minimize potential credible accidents. As part of the Shuttle/Agena Study, a safety analysis and assessment was performed to identify possible hazards and substantiate the belief that a minimum risk operation can be achieved on shuttle flights involving the Agena space tug.

7.1 SAFETY REQUIREMENTS AND GUIDELINES

The guidelines and safety criteria enumerated here were obtained from NASA MSC in order to interpret the meaning of "man-rating" with respect to the space tug concept.

Man-rating can be defined as the method that assures that manned systems have met the requirements established for safety and man-machine relationships so that the system/hardware can be officially certified as suitable for man's use. Within the scope of this study the tug remains an unmanned vehicle, which is launched by a manned vehicle and operates at times in relative proximity to man. Thus the tug must be man-rated to the extent that it does not violate any shuttle man-rating requirements.

The unmanned tug mission (launched in shuttle orbiter cargo bay) requires manned interfaces during ground handling outside and inside the launch vehicle; preservation of a passive role during launch; capability of EOS-commanded check, unloading, activation, separation, rendezvous, docking/on-loading, safety preparations, and deactivation; preservation of a passive role during reentry and landing; and capability

of being approached, passivated, and inspected for post-flight status. Potential personnel emergencies caused by the tug could occur at any time on the ground, inside the EOS cargo bay, and in free flight near the EOS.

The following preliminary safety criteria have been established for evaluating tug operations within the manned shuttle environment:

a. The tug, either in an active or a dormant state, shall not degrade the safety of the space shuttle nor violate established shuttle safety levels and requirements.

b. Catastrophic and critical hazards shall be eliminated, reduced to controlled hazards, or identified as residual hazards with a rationale provided.

c. For those hazards that may result in time-critical emergencies (an emergency which must be detected and corrective action initiated for within 5 minutes or less to prevent failure of a critical function) provisions shall be made for automatic switching to a safe mode and to display caution and warning to shuttle personnel.

d. The tug shall provide the capability of being rendered safe in the event of an abort. This will include pyrotechnic disarmament and fluid jettisoning.

e. The tug shall provide such information to the shuttle as is necessary, in its status as a payload, to ensure safe shuttle operation.

f. Tug elements containing hazardous materials or devices shall have self-contained protective provisions against all hazards.

g. All tug subsystems except primary structure and pressure vessels shall be designed to fail safe for crew survival after any single failure.

h. All tug subsystems incorporating redundancies shall include a means of verifying satisfactory operations of each redundant path.

i. Where practicable, shuttle design safety factors shall be used to establish tug design pressures and loads. Areas not meeting this criteria shall be identified and rationale provided.

j. Inadvertent activation of critical tug systems, either active or dormant, shall be inhibited by design of systems and/or protective devices.

The objective of the safety criteria is to assure the compatible application of an unmanned tug space vehicle in a manned vehicle environment.

To ensure safety of the orbiter/Agena combination the following specific requirements were established as guidelines for the Agena space tug design.

7.1.1 Structural Integrity

The Agena structural integrity shall provide a safety factor (of 1.5) for all loading conditions that will occur when the Agena is mounted in the orbiter cargo bay. The conditions shall include propellant tanks empty and propellant tanks full but unpressurized.

7.1.2 Loading of Hazardous Materials

Propellants, high-pressure gases, and explosive devices shall be loaded in or on the Agena and absence of leaks shall be established before the Agena is mated to the shuttle orbiter.

7.1.3 Pyrotechnic Devices

All pyrotechnic devices shall be properly protected to prevent actuation from electromagnetic and electrostatic sources. All electrical wiring shall be adequately shielded and all components grounded. A pyrotechnic device in the shuttle bay shall be activated only by deliberate, intended action on the part of the shuttle crew. EMI Control Plan 1420793, with appropriate modifications, shall be observed.

7.1.4 Propellant Dump

Provisions shall be made for safe dumping of Agena propellants, within 15 minutes of initiation, while the Agena is in the cargo bay of a shuttle in orbit.

7.1.5 Agena Jettison Provisions

Provision shall be made for jettisoning the Agena/payload as a backup safety measure when the shuttle is outside the earth's atmosphere.

7.1.6 Safety Instrumentation

Instrumentation shall be provided in the Agena and the shuttle cargo bay, as appropriate, to monitor pressures of stored gases, cargo bay temperature, pressures and temperatures of propellants, and to detect propellant leaks.

7.1.7 Payload Separation

The separation distance required between the shuttle and the Agena prior to Agena main engine startup shall be determined on the basis of shuttle safety criteria and contamination constraints.

7.2 HAZARD IDENTIFICATION AND ANALYSIS

7.2.1 Hazard Identification

The principal hazards of concern in the use of an Agena vehicle as a payload in the orbiter cargo bay are those related to the presence of (1) high-pressure gas storage containers; (2) large quantities of high-energy, toxic, hypergolic propellants; and (3) pyrotechnic devices. Operations that may be hazardous if not properly planned and executed were examined and the potential hazards are identified in Table 7-1. The major hazards are those associated with the use of unsymmetrical dimethyl-hydrazine (UDMH) as fuel and inhibited red fuming nitric acid (IRFNA) as oxidizer.

UDMH vapor inhalation is most dangerous, although this fuel can also be absorbed into the body through the skin and by ingestion. The effects of UDMH are severe irritation of mucous membranes of eyes, respiratory passages, and lungs; stimulation of the central nervous system resulting in convulsions; irritation of the gastro-intestinal tract, nausea; and emesis. In sufficient quantities, inhalation of UDMH can cause direct destruction of red blood cells.

Table 7-1

AGENA SPACE TUG HAZARD IDENTIFICATION

Operation	Hazard	Remarks
Load propellants, gases, and pyrotechnics	Bulkhead rupture; propellant spills or leakage	Normal O/F Tank Pressure differential must be maintained
Ground Handling and Transport Options: a. From vertical, tanked, to horizontal mating with shuttle and then move to pad. b. From horizontal, empty, to horizontal mating with the shuttle, followed by tanking and then transport to pad. c. Mate to shuttle and transport to pad with empty tanks.	a. and b.: Improper design, handling, accelerations, supports, and load distribution could result in propellant leaks or tank rupture c: None	Propellant temperatures must be controlled and monitored to avoid need for venting. Handling procedures, safeguards, and emergency countermeasures must be developed.
On-Pad – Prelaunch Systems Check Propellant Emergency Dump	Propellant leaks, high-pressurization gas tank rupture, activation of propellant dump	Improper fill, pyro installation or handling, or systems checks could result in tank rupture, leaks, or dump. Design and procedures must be carefully controlled. High-pressure gas bottle design load margins should meet shuttle requirement. Electrical grounding must be provided through the shuttle to earth ground. Provisions must be made for emergency dump and disposal of propellants.
Shuttle Ascent and Orbit	Tank Pressurization: Bulkhead Reversal Tank Rupture Propellant Leaks Agena Structural Support: Excessive Deflections and Tank Stresses Structural Failure O_2 Concentration in Cargo Bay	Propellant temperature/pressure must be controlled to avoid venting or tank rupture. Pyrotechnics must be safed. Orbiter cargo bay must be vented. Agena structural supports must be designed to transfer all loads without excessive stresses or deflections. Oxygen gas from the orbiter may contribute to an explosion if allowed to concentrate in the cargo bay – explosive in the presence of hydraulic fluid carried by Agena.

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Table 7-1 (cont)

Operation	Hazard	Remarks
Mission Abort	Dump system failure Tanks ruptured on hard landing	Agena propellants should be dumped prior to landing. Propellants must not be joined in hypergolic mixtures. Oxidizer flow should start before fuel. Dump lines should be at the same longitudinal station and separated laterally as far as practical. Harmless flashes will probably occur on simultaneous O/F dump in atmosphere. Dump rate must be increased over standard Agena. Propellants must be settled in the tanks during dump. High-pressure gas bottle design load margins should meet shuttle requirements.
Agena Deployment and Post-Deployment	Presence of immobile Agena, with propellant dump lines disconnected, following failure of deployment mechanism, or physical jamming of Agena/payload in the cargo bay Collision during separation Rocket exhaust impingement on Shuttle Collision following loss of control of Agena after main engine ignition	Deployment failure might create a situation where all options such as re-securing Agena, propellant dump, Agena jettison, and cargo bay door closing were removed. Improper deployment provisions and procedures may result in collision. Inadequate separation between Agena and shuttle at time of Agena engine ignition could result in impingement of exhaust products on the shuttle and in structural damage. Loss of Agena attitude control following main engine ignition could result in collision with the Shuttle.
Agena-Shuttle Rendezvous	Collision	Collision may result from improper trajectory or from spacecraft tumbling. Main tank propellants may be dumped prior to rendezvous. Agena must provide attitude stabilization. Spent Agena left in earth orbit constitutes a subsequent hazard of collision.

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IRFNA (both liquid and vapor) is highly toxic in high concentrations. Breathing the vapor may cause severe damage to the nose, throat, respiratory passages, and lungs. In contact with the skin or eyes, nitric acid causes severe burning; in the case of the eyes, possible destruction of the eye tissues can occur, with subsequent blindness. IRFNA also vigorously attacks most metal and organic materials and in concentrated form may cause spontaneous ignition and vigorous burning when in contact with organic materials.

Liquid IRFNA is hypergolic when combined with liquid UDMH.

Most of these hazards are associated with the presence of high-pressure gases and hypergolic propellants; they can be adequately handled through adaptation of existing Agena procedures.

7.2.2 Agena Safety History

Procedures for the safe storage, transfer, handling, and use of the propellants used in the Agena vehicle have been well developed and demonstrated over a period of 12 years, in which over 300 vehicles were launched. These procedures can be adapted to use of the Agena in the shuttle with complete confidence that safety for ground and flight crews has been provided.

As an indication of the confidence that can be placed on the integrity of the Agena propellant system, detailed records of propellant leaks show the following:

a. At the Western Test Range, 194 Agenas have been launched since 1962 with no vehicle leaks. No ground support equipment (GSE) leaks have occurred since 1969, and leaks prior to that date were minor or negligible. (Records are not available for launches prior to 1962.)

b. At the Eastern Test Range, 42 Agenas have been launched with no vehicle leaks. No GSE leaks have occurred since 1962.

c. At Lockheed's Santa Cruz Test Base, 34 Agenas have been hot-fired with no vehicle leaks. Records of GSE leaks are not available.

Of the more than 300 Agena flights using hypergolic propellants, three have provided experience relating to Agena reliability, safety, handling, and operational considerations for the space tug application.

In the first experience (1960-61), a fire in the aft rack was attributed to fuel leaking from the bellows during ascent. The fuel burned with air after an electrical short ignited the mixture. This type of fire could result with any fuel – hypergolic or not. As a consequence of this experience, propellant sniffers have been installed to detect propellant vapors in the booster adapter prior to liftoff.

In the second experience (1961-62), a failure occurred in which both propellants were simultaneously dumped onto the engine nozzle for approximately 1,000 seconds, producing high torque from a resultant reaction. In vacuum, sequential separation of dumped propellants is employed. In all dumping operations, the oxidizer dumping is normally started first. Delaying initiation of fuel dumping prevents simultaneous liquid dumping and keeps vehicle torques well within the capability of the pneumatic attitude control system.

Ground tests in 1962 (dump vent simulation tests) demonstrated that no explosive characteristics or violent reactions occur when the propellants are injected into an evacuated closed chamber at low flow rates. On the basis of these tests, on subsequent missions the propellants were simultaneously vented to vacuum with exits approximately 5 inches apart. No deleterious torques (reactions) have been experienced during these vent operations or during missions in which propellants are dumped after final burn.

In the third experience, during Gemini flights, astronauts handled, operated, and inspected the Agenas in orbit with pressurized propellant aboard. These preliminary tug studies indicate that no major changes to the Agena need be considered because of the use of hypergolic propellants.

7.2.3 Single-Point Failure Analysis

Single-point failure analysis on the ascent Agena, reported in LMSC-A972281,* dated July 21, 1970, reveals no single-point failure mode of concern to manned safety of the Agena configuration as adapted to use in the space shuttle.

A single-point failure analysis of shuttle/Agena interface items reveals the need for attention in the following areas:

a. The Agena support/constraint system must be designed for release only after separate actions to unground the release circuit, arm the release circuit, and initiate the release command.
b. The Agena/shuttle interface disconnects for electrical power, status and command hardlines, and propellant emergency dump lines should be designed for release after separate actions to unground the disconnect circuit, arm the disconnect circuit, and initiate the disconnect command. The most critical requirement is assurance that propellant lines could not be disconnected during an emergency dump.

It is further recommended that manual backup be provided for all Agena/shuttle interface and support/constraint connect and disconnect functions.

7.2.4 Hazard Analysis Results

An analysis of the hazards identified in Table 7-1 resulted in the following recommended actions:

a. Check all design load margins to ensure compatibility with Agena man-rating requirements.
b. Provide for emergency propellant dump at any time between shuttle liftoff from the pad and departure from orbit for reentry. Propellant dump should be accomplished in 15 minutes or less, to ensure empty tanks prior to shuttle orbiter landing.
c. Delay engine firing until the Agena has been separated a distance of 1/2 mile or more from the shuttle.

*Reliability Analysis Report for Detail Design Review Program 711 Stage III Vehicle, Contract F04701-69-C-0338

d. Purge the orbiter cargo bay from time of installation of Agena until launch, to prevent concentration of gases in the event of shuttle or Agena propellant leaks.

e. Provide instrumentation to read stored gas pressure, propellant tank pressures and temperatures, differential pressure between oxidizer and fuel tanks, shuttle bay temperature, and presence of oxidizer or fuel in the cargo bay and in dump lines.

7.3 SAFETY ENHANCEMENT

The shuttle-Agena space tug mission safety can be enhanced by eliminating certain design and/or procedural deficiencies that could lead to the hazard conditions previously described.

7.3.1 Recommended Modifications for Agena Safety

The following modifications and additions to the basic Agena vehicle are suggested:

a. Modify the propellant fill coupling poppet valves to be normally open when connected to the shuttle emergency propellant dump lines.

b. Provide an oxidizer tank pressure relief valve, activated by differential pressure between oxidizer tank and fuel tank, to maintain oxidizer tank pressure equal to or below that in the fuel tank. Connect the relief valve outlet to the vehicle oxidizer fill line. This installation is illustrated in Fig. 7-1.

c. Provide a valve in the vent port line connected to the oxidizer propellant isolation valve as indicated in Fig. 7-1. This valve remains closed at all times until after Agena deployment from the shuttle in orbit and prevents vented oxidizer from entering the shuttle cargo bay. The valve is opened prior to initiation of Agena engine first start and remains open thereafter.

d. Install pressure transducers to measure oxidizer and fuel storage tank pressures.

e. Install temperature pickups on the exterior skin of fuel and oxidizer tanks.

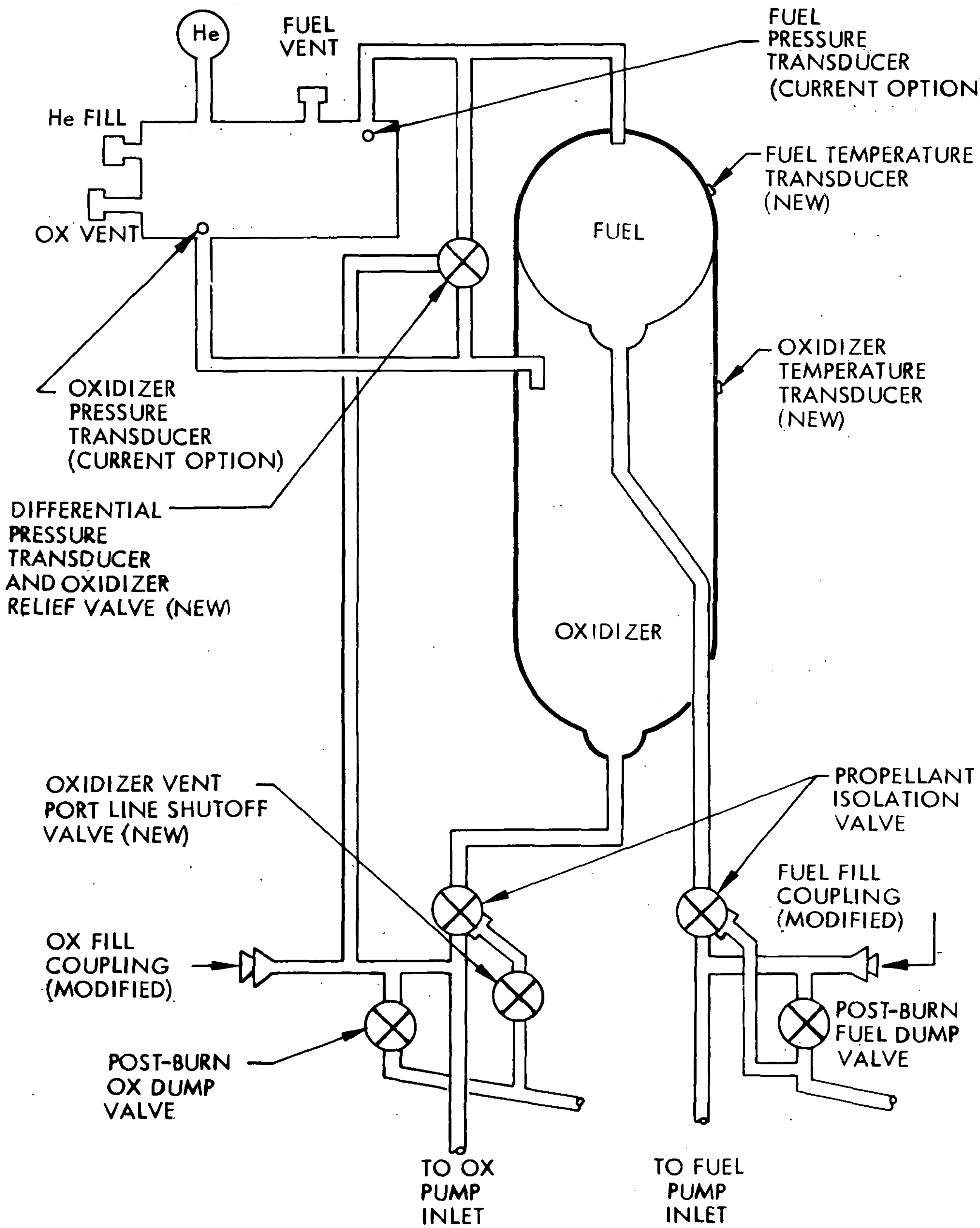


Fig. 7-1 Agena Modifications for Safety

7.3.2 Recommended Procedural Constraints for Agena Tug Safety

It is suggested that the following system configurations be adopted in the procedures that will govern Agena operations during the period from propellant loading until Agena deployment on orbit.

The change in Agena configuration with each operation may be understood by referring to Fig. 7-1.

a. Load Propellants

Post-burn dump valves closed

Oxidizer vent port line shutoff valve closed

Fuel fill connected and open

Fuel PIV (propellant isolation valve) open

Fuel vent connected and open

Oxidizer fill connected and open

Oxidizer PIV open

Oxidizer vent connected and open

b. Propellants Loaded

Fuel PIV closed

Fuel fill disconnected after line drained and purged; poppet valve closed by disconnect

Fuel vent disconnected and poppet closed

Oxidizer PIV closed

Oxidizer fill disconnected after line drained and purged; poppet valve closed by disconnect

Oxidizer vent disconnected and poppet closed

(Transport to Shuttle in Configuration 2)

c. Mate to Shuttle

Same as Configuration 2 except:

Oxidizer fill connected to oxidizer dump line at Shuttle interface

Fuel fill connected to fuel dump line at Shuttle interface

(Deploy From Shuttle in Configuration 2)

d. Pre-Agena Propulsion Burn

(Configuration 2, except open oxidizer vent port line shutoff valve)

7.4 SAFETY INSTRUMENTATION

Safety instrumentation associated with transport of an Agena in the cargo bay of a space shuttle should provide information concerning the hazards of fire, explosion, and contamination. The following parameters are among those to be monitored:

a. Pressure in Gas Storage Tanks
b. Pressures and Temperatures in Propellant Tanks
c. Differential Pressure Between Stored Fuel and Oxidizer
d. Temperature in the Shuttle Cargo Bay
e. Detection of Fuel or Oxidizer Leaked Into the Shuttle Cargo Bay or Emergency Dump Lines

Table 7-2 presents a list of instruments recommended, and includes sensor location, instrument range, acceptable readings, and action required if instrument reading is out of range. These instruments are discussed in the following paragraphs.

Pressures of stored fuel and oxidizer can be monitored by use of instruments that have been flight proven on the Agena. These instruments are optional on current Agena flights. The propellant pressures should be monitored to ensure that operating limits are not exceeded. If pressures are excessive, they must be reduced by lowering propellant temperatures or by propellant dump. Oxidizer pressure may also be lowered by venting.

New instrumentation will be required to measure propellant temperatures. The sensors may be attached to the external skin of fuel and oxidizer tanks as illustrated in Fig. 7-1. Monitoring of temperatures, when correlated with pressures, will help to establish whether a pressure rise is caused by heating or by a pressurization system leak, and thus help determine whether cooling, venting, or dumping is required.

The measurement of differential pressure between fuel and oxidizer tanks is important in ensuring that the common bulkhead is not damaged by reversal. If oxidizer pressure exceeds fuel pressure at any time, oxidizer must be cooled, vented, or dumped to restore the desired pressure differential. Venting can be accomplished automatically through the proposed differential pressure oxidizer relief valve.

Table 7-2

SAFETY INSTRUMENTATION

MEASUREMENT	LOCATION	INSTRUMENT RANGE	ACCEPT. READINGS	ACTION REQUIRED IF READING OUT OF RANGE
Fuel Tank Pressure	In pressurization control valve	0 to 100 psi	0 to 46 psi	Reduce Fuel Temperature or Dump.
Oxidizer Tank Pressure	In pressurization control valve	0 to 100 psi	0 to 46 psi	Reduce Oxidizer Temperature, Vent, or Dump.
Fuel Tank Temperature	Exterior Tank Skin	30° to $90^{\circ}F$	$\leq 75^{\circ}F$	Reduce Fuel Temperature or Dump.
Oxidizer Tank Temperature	Exterior Tank Skin	30° to $90^{\circ}F$	$\leq 75^{\circ}F$	Reduce Oxidizer Temperature, Vent or Dump.
Oxidizer Fuel Differential Pressure	Between Oxidizer and Fuel Vent Lines	±10 psi	Fuel Minus Oxidizer ≥ 0 psi	Cool, Vent, or Dump Oxidizer.
Cargo Bay Temperature	Shuttle Cargo Bay	TBD	TBD	TBD
Presence of Fuel or Oxidizer	Shuttle Cargo Bay and Propellant Dump Lines	TBD	Negative	Assess leak rate and, if out of acceptable range, either deploy Agena or dump propellant, as appropriate.
He Tank Pressure	He Control Valve	0 to 4,000 psi	2,880 psi	Cool or Vent.
N_2 Tank Pressure	N_2 Control Valve	0 to 4,000 psi	2,880 psi	Cool or Vent.

The measurement of temperature in the shuttle cargo bay is useful in anticipating and avoiding temperature changes in the Agena propellants. The number and locations of temperature pickups required is a subject for further study.

Instrumentation to detect the presence of fuel or oxidizer that has leaked into the shuttle cargo bay may be divided into two categories:

a. Leakage detection while Agena is in the shuttle cargo bay during preparation for launch and while a sensible atmosphere remains in the bay during ascent
b. Leakage detection on orbit with the shuttle cargo bay evacuated

Leakage detection for the first category can be achieved with the use of sensors similar in general character to a mass spectrometer but of much smaller size and simpler operational principal. Separate sensors will be required for the UDMH and the IRFNA. This type of sensor is available from American Systems, Incorporated, and from Leeds and Northrup Company. The system could function during prelaunch and ascent by sampling the cargo compartment purging gas as it is vented through an opening in the cargo door.

Leakage detection while in orbit will be more difficult, since the cargo bay doors will be open and the bay evacuated. Further study is required to devise satisfactory instrumentation for the condition, but catalyst cartridges in the vicinity of points of potential leakage have been suggested. It may also be possible to show that a leak big enough to present a potential hazard can be detected by monitoring tank temperature and pressure and calculating any change in mass of propellant contained. If catalyst cartridges are used, a total of four should be adequate. This would include one each for oxidizer and fuel mounted in the Agena aft rack adjacent to the propellant isolation valves and a similar pair mounted in the Agena forward rack adjacent to the helium control valve and differential pressure vent valve.

In addition to the leak detectors discussed above, sensors should be included in the shuttle emergency propellant dump lines to detect any leakage across the propellant isolation valves.

7.5 RECOMMENDATIONS FOR FURTHER STUDY

Agena tug safety analyses conducted during the study revealed the need for additional work when resources become available. It is recommended that the following items be given consideration:

a. Study space shuttle abort under all conditions to establish acceptable Agena propellant dump time requirements.

b. Extend analysis of simultaneous dump of Agena oxidizer and fuel to confirm acceptability under abort dump flow rates.

c. Perform a detailed hazards analysis of Agena and shuttle/Agena interface with the modifications, additions, and operations recommended as a result of the current study. Work from a detailed sequence of events, starting with loading of propellants and other hazardous materials and ending with deployment and spacing in orbit, and perform a comprehensive safety analysis of each event and configuration.

d. Study means for accurate detection of propellant leaks in the shuttle bay and in emergency dump lines at all times, from mate to deployment of the Agena, and for determining the rate of any such leak.

Section 8
COST ANALYSIS

Section 8
COST ANALYSIS

To complete analysis of the Agena space tug, cost estimates were derived for the various reference Agena tug configurations developed during the course of the study. The results of Lockheed's cost analysis are presented in this section. First, the guidelines and assumptions used in formulating the Agena tug cost estimates are enumerated; these are of critical importance to the proper understanding and interpretation of the costs. Next, the costing methodology is reviewed, and the work breakdown structure (WBS) used in the study is presented. With this background information established, results of three specific areas of the cost analysis follow; the first is costs for the baseline Agena space tug, then for the evolutionary Agena tug, and finally for the 30-day low earth orbit version of the baseline Agena tug.

8.1 GUIDELINES AND ASSUMPTIONS

The costs presented in this section are entirely contingent on the guidelines and assumptions enumerated here. Any changes can be expected to alter the results significantly.

The following general guidelines were observed in the cost analysis:

a. All costs were expressed in constant year dollars and all rates were typical current year (1971-72) values.

b. Unit recurring costs quoted were average values for the specified production rates. Theoretical first unit costs and learning effects were excluded, because production rate variations have a greater influence than has learning on the cost of a mature space vehicle such as Agena. (The first Agena production unit was manufactured before 1960.)

Important programmatic assumptions made in deriving the Agena space tug costs were as follows:

a. A production rate of six per year over a program duration of 12 years was assumed in deriving the unit costs. Higher launch rates, such as might be anticipated in a full-scale space shuttle program, will reduce the quoted costs. Rate effects on production are considered in the analysis.

b. It was assumed that the Agenas will be purchased by NASA directly from LMSC. No dual-agency program management, such as was experienced on the Gemini-Agena program, would be incorporated on the Agena space tug.

c. The baseline Agena tug configuration for costing purposes was an ascent vehicle only; integrated-spacecraft versions were considered separately.

d. The development program for the Agena space tug was assumed to include one flight test; consequently, costs for one flight test article and its associated operations were included. However, no charge was made for the use of the space shuttle during this flight test.

e. Ground test operations were considered to require one equivalent vehicle plus a partial set of component/subsystems test hardware.

f. It was assumed that six sets of shuttle interface equipment to accommodate the Agena space tug would be purchased; five of these would be for flight purposes and one set would be used as backup.

Important cost elements included in the Agena tug costs were as follows:

a. Services and software that are mission peculiar; that is, those services that enable the Agena space tug to fly a particular mission with a particular payload (Such services would include guidance software, documentation, and mission plans.)

b. Launch costs for the Agena; that is, the costs of sustaining the Agena launch crew, and any facilities and GSE required to support Agena operations only

Specific cost elements omitted from these estimates included the following:

a. Prime contractor fee (however, subcontractor fee was included.)

b. Government costs for program management, mission control, and tracking network operations

c. Space shuttle launch operations

8.2 METHODOLOGY

The methodology used to derive Agena tug costs was a bottom-up approach, featuring extensive cross reference to Agena historical cost data.

The first step in the analysis was to build a hardware-end-item-oriented Work Breakdown Structure (WBS) that could serve as a framework for the collection and indentured summation of costs. The WBS that was generated for this study (Fig. 8-1) conforms to the general format requirements and the numerical indexing plan presented in NASA Data Requirement Description MF002M "Document, Project Cost and Schedule Estimates, Phase B," dated 24 April 1969. This WBS is structured for six levels of costing (designated as Levels 2 through 7 in MF002M, because Level 1 is reserved for NASA use). Special effort was made to keep the Agena tug WBS structure format compatible with the WBS used in the Gemini Agena Cost, Schedule and Technical Characteristics Study, a principal source of cost data for the Agena tug cost analysis. Some of the Agena tug WBS entries whose meaning may not be immediately evident are as follows:

a. Subsystems Installation and Checkout: This entry comprises final assembly and acceptance test.
b. Logistics: This entry includes spares, transportation, propellants, and logistics services.
c. Support: This item collects miscellaneous charges for travel, reproduction, computer, personnel allowances, etc.

This WBS was used as a framework for estimating input data – in the form of labor hours (by classification) as well as material and subcontract costs – for all the WBS items at the lowest levels of indenture. For hardware items this lowest WBS indenture was often Level 7 (component level).

Next, the bottom level entries were keypunched and supplied as inputs to LMSC's computer program DBANK. The DBANK program then performed calculations to convert the elements of cost to dollar costs (by WBS entry), using current rates and applicable ratios, such as the ratio of quality assurance to manufacturing and test planning to test operations. The logic of the DBANK program next summed the costs

upward by levels to produce summary level totals for the Agena tug program. The costs were estimated not only by WBS entry but by program phase, i.e., recurring production, recurring operations, and nonrecurring costs.

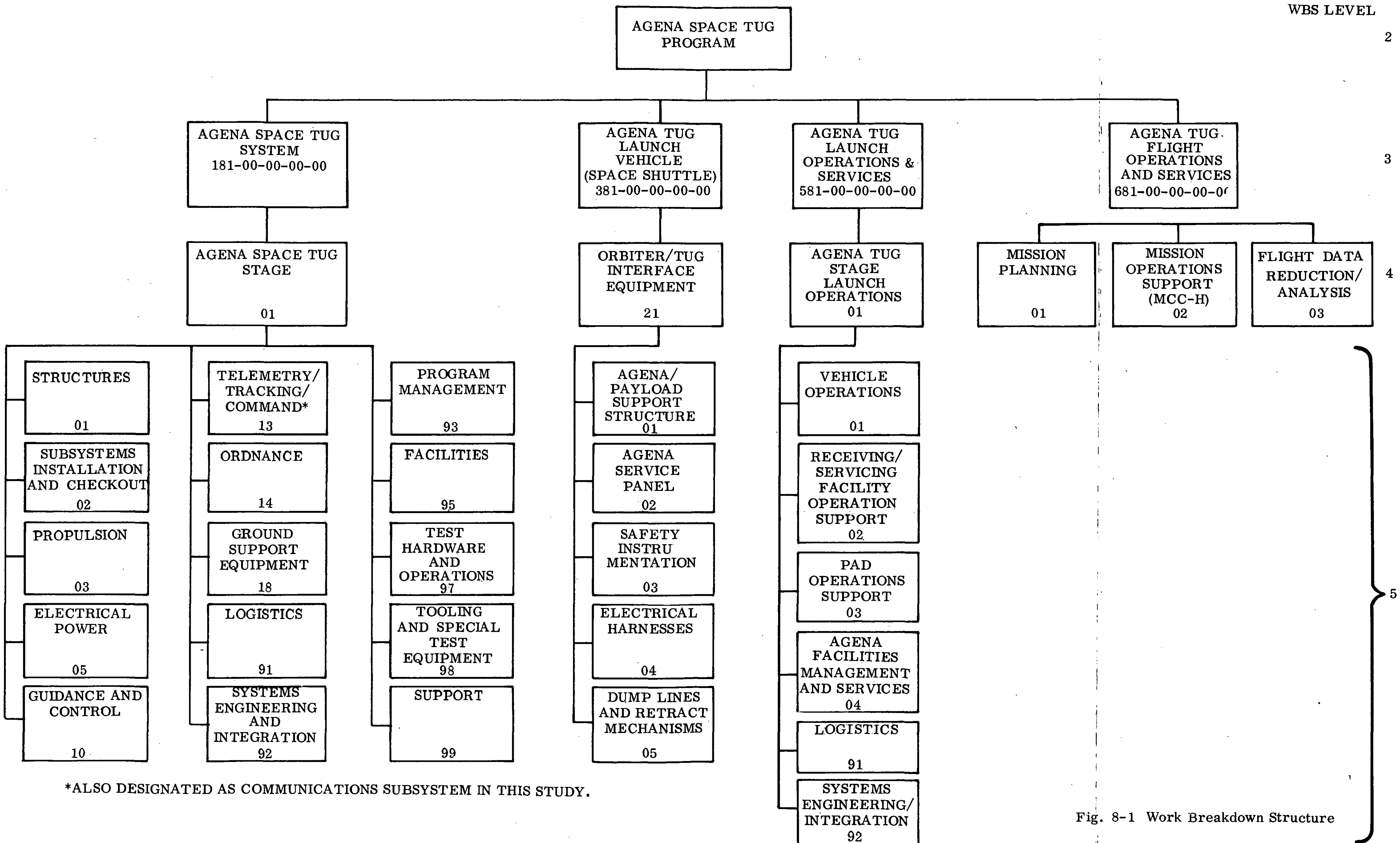
Sources of cost and manpower data used in deriving the bottom level costs included recent information on expenditures for ascent versions of the Agena as well as a detailed historical study of the Gemini Agena Target Vehicle. The latter study, conducted for NASA/MSC on Contract NAS9-10902, contained manpower and material records down to Levels 7 and 8 of WBS indenture.

As a final check on the estimates derived in the manner described above, a series of independent cost reconciliation analyses was conducted to compare the projected recurring and nonrecurring costs for the Agena tug against a historical reference point, the Gemini Agena Target Vehicle. Costs were adjusted in these reconciliations to account for differences in configuration and in monetary factors (i.e., the rate structure and other inflationary effects).

8.3 RESULTS

8.3.1 Baseline Agena Tug

The estimated costs for the baseline version of the Agena tug (5-foot diameter, ascent mission capability only) are summarized in Table 8-1. This table is a direct computer printout from the DBANK program of the indentured costs by WBS entry. Costs for all the program phases (recurring and nonrecurring) are discussed at greater length in the following paragraphs.



*ALSO DESIGNATED AS COMMUNICATIONS SUBSYSTEM IN THIS STUDY.

Fig. 8-1 Work Breakdown Structure

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Table 8-1

BASELINE AGENA SPACE TUG COST SUMMARY

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
01 00 00	(5)	STRUCTURES	0.	0.	0.	0.	0.	0.	
181 00 00 00 00	(3)	AGENA SPACE TUG SYSTEM	8062.	155060.	0.	0.	25000.	450875.	
01 00 00 00	(4)	AGENA SPACE TUG STAGE	8062.	155060.	0.	0.	25000.	450875.	
01 00	(6)	SUBSYSTEM INTEGRATION	2000.	36070.	0.	0.	25000.	450875.	
02 00	(6)	FORWARD SECTION	1375.	31857.	0.	0.	0.	0.	
03 00	(6)	PROPELLANT TANK ASSEMBLY	2625.	46813.	0.	0.	0.	0.	
04 00	(6)	AFT SECTION	1250.	25740.	0.	0.	0.	0.	
05 00	(6)	ATTACHMENT RING	250.	4769.	0.	0.	0.	0.	
06 00	(6)	MISCELLANEOUS STRUCTURES	563.	9811.	0.	0.	0.	0.	
02 00 00	(5)	SUBSYSTEMS INSTALLATION/CHECKOUT	10545.	184251.	0.	0.	0.	0.	
01 00	(6)	FINAL ASSEMBLY AND INSPECTION	2500.	41762.	0.	0.	0.	0.	
02 00	(6)	POST-ACCEPTANCE PROCESSING	250.	4176.	0.	0.	0.	0.	
97 00	(6)	ACCEPTANCE TESTING	7795.	138312.	0.	0.	0.	0.	
01	(7)	AMBIENT FUNCTIONAL TEST	5603.	99412.	0.	0.	0.	0.	
02	(7)	THERMAL/VACUUM TEST	2192.	38900.	0.	0.	0.	0.	
03 00 00	(5)	PROPULSION	1556.	614161.	0.	0.	35000.	631225.	
01 00	(6)	SUBSYSTEM INTEGRATION	1000.	18035.	0.	0.	35000.	631225.	
02 00	(6)	PRIMARY PROPULSION SYSTEM	556.	596126.	0.	0.	0.	0.	
01	(7)	MODEL 8247 ENGINE	0.	535600.	0.	0.	0.	0.	
02	(7)	PROPELLANT ISOLATION VALVES (2)	0.	14220.	0.	0.	0.	0.	
03	(7)	PROPELLANT DUMP VALVES (2)	0.	11850.	0.	0.	0.	0.	
04	(7)	PROPELLANT FILL COUPLINGS (2)	0.	829.	0.	0.	0.	0.	
05	(7)	PROPELLANT VENT COUPLINGS (2)	150.	2541.	0.	0.	0.	0.	
06	(7)	PROPELLANT LINES/PLUMBING INTEGRAT	250.	7968.	0.	0.	0.	0.	
07	(7)	FAST SHUTDOWN KIT	125.	2207.	0.	0.	0.	0.	
08	(7)	HELIUM SUPPLY SPHERE	0.	5214.	0.	0.	0.	0.	

Table 8-1 (Cont.)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
09	(7)	HELIUM PRESSURE REGULATOR	0.	11850.	0.	0.	0.	0.	
10	(7)	HELIUM FILL COUPLING	31.	528.	0.	0.	0.	0.	
11	(7)	PYRO HELIUM CONTROL VALVE	0.	3318.	0.	0.	0.	0.	
05 00 00	(5)	ELECTRICAL POWER	3920.	91260.	0.	0.	12000.	216420.	
01 00	(6)	SUBSYSTEM INTEGRATION	1800.	32463.	0.	0.	12000.	216420.	
02 00	(6)	POWER SUPPLY SYSTEM	0.	10072.	0.	0.	0.	0.	
01	(7)	PRIMARY BATTERIES TYPE IV-B	0.	2962.	0.	0.	0.	0.	
02	(7)	PRIMARY BATTERY,TYPE I-H *	0.	7110.	0.	0.	0.	0.	
03	(7)	SECONDARY BATTERY,TYPE VI-A **	0.	0.	0.	0.	0.	0.	
04	(7)	SOLAR ARRAY **	0.	0.	0.	0.	0.	0.	
05	(7)	CHARGE CONTROLLER **	0.	0.	0.	0.	0.	0.	
03 00	(6)	POWER DISTRIBUTION SYSTEM	2120.	48724.	0.	0.	0.	0.	
01	(7)	POWER DISTRIBUTION J-BOX	385.	10087.	0.	0.	0.	0.	
02	(7)	AFT CONTROL/INSTRUMENTATION J-BOX	392.	8310.	0.	0.	0.	0.	
03	(7)	PYROTECHNIC CONTROL J-BOX	592.	10925.	0.	0.	0.	0.	
04	(7)	ELECTRICAL HARNESSING	750.	19402.	0.	0.	0.	0.	
10 00 00	(5)	GUIDANCE AND CONTROL	3361.	627957.	0.	0.	20000.	360700.	
01 00	(6)	SUBSYSTEM INTEGRATION	1200.	21642.	0.	0.	20000.	360700.	
02 00	(6)	GUIDANCE SYSTEM	325.	510248.	0.	0.	0.	0.	
01	(7)	INERTIAL SENSOR ASSEMBLY	0.	288400.	0.	0.	0.	0.	
02	(7)	COMPUTER	0.	216300.	0.	0.	0.	0.	
03	(7)	GUIDANCE MODULE	325.	5548.	0.	0.	0.	0.	
03 00	(6)	FLIGHT CONTROLS SYSTEM	1805.	40674.	0.	0.	0.	0.	
01	(7)	FLIGHT CONTROL ELECTRONICS PKG	1805.	40674.	0.	0.	0.	0.	
04 00	(6)	STABILIZATION CONTROL SYSTEM **	0.	0.	0.	0.	0.	0.	
01	(7)	HORIZON SENSOR ASSEMBLIES (2) **	0.	0.	0.	0.	0.	0.	

*Mission-peculiar to synchronous equatorial mission
**Mission-peculiar to 30-day low earth orbit mission

Table 8-1 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
~~02~~	~~(7)~~	~~GYRO REFERENCE ASSEMBLIES (2) **~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	0.	
03	(7)	ORBIT ELECTRONICS ASSEMBLY **	0.	0.	0.	0.	0.	0.	
04	(7)	AUGMENTED ELECTRONICS ASSEMBLY **	0.	0.	0.	0.	0.	0.	
~~05~~	~~(7)~~	~~DACS MODULE **~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	0.	
05 00	(6)	HYDRAULIC SYSTEM	0.	19315.	0.	0.	0.	0.	
01	(7)	HYDRAULIC POWER PACKAGE	0.	10783.	0.	0.	0.	0.	
~~02~~	~~(7)~~	~~HYDRAULIC ACTUATORS (2)~~	~~0.~~	~~8532.~~	~~0.~~	~~0.~~	~~0.~~	0.	
06 00	(6)	REACTION CONTROL SYSTEM	31.	36078.	0.	0.	0.	0.	
01	(7)	NITROGEN SUPPLY SPHERE	0.	5214.	0.	0.	0.	0.	
~~02~~	~~(7)~~	~~NITROGEN PRESSURE REGULATOR~~	~~0.~~	~~17775.~~	~~0.~~	~~0.~~	~~0.~~	0.	
03	(7)	NITROGEN THRUSTERS (2)	0.	12561.	0.	0.	0.	0.	
04	(7)	NITROGEN FILL COUPLING	31.	528.	0.	0.	0.	0.	
~~05~~	~~(7)~~	~~DACS NITROGEN SPHERE **~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	0.	
06	(7)	DACS NITROGEN REGULATOR **	0.	0.	0.	0.	0.	0.	
07	(7)	DACS NITROGEN THRUSTERS (2) **	0.	0.	0.	0.	0.	0.	
~~08~~	~~(7)~~	~~DACS NITROGEN PLUMBING **~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	0.	
13 00 00	(5)	TELEMETRY,TRACKING AND COMMAND	7415.	220215.	0.	0.	60000.	1082100.	
01 00	(6)	SUBSYSTEM INTEGRATION	3500.	63122.	0.	0.	60000.	1082100.	
~~02 00~~	~~(6)~~	~~TELEMETRY/TRACKING SYSTEM~~	~~915.~~	~~76199.~~	0.	~~0.~~	~~0.~~	0.	
01	(7)	PCM TELEMETRY MODULE,TYPE IV	0.	9835.	0.	0.	0.	0.	
02	(7)	BASEBAND ASSEMBLY	0.	14220.	0.	0.	0.	0.	
~~03~~	~~(7)~~	~~UHF TRANSMITTER,2-WATT~~	~~0.~~	~~17775.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	
04	(7)	POWER AMPLIFIER *	0.	5925.	0.	0.	0.	0.	
05	(7)	MULTICOUPLER,TYPE 14	0.	3199.	0.	0.	0.	0.	
~~06~~	~~(7)~~	~~RF SWITCH,TYPE 14~~	~~0.~~	~~6991.~~	~~0.~~	~~0.~~	~~0.~~	0.	
07	(7)	ANTENNA,TYPE 28	72.	1256.	0.	0.	0.	0.	

Table 8-1 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
08	(7)	ANTENNA,PARABOLIC *	300.	5233.	0.	0.	0.	0.	
09	(7)	TELEMETRY J-BOX	542.	11764.	0.	0.	0.	0.	
03 00	(6)	COMMAND SYSTEM	3000.	73665.	0.	0.	0.	0.	
01	(7)	COMMAND RECEIVER/DEMODULATOR	0.	17775.	0.	0.	0.	0.	
02	(7)	COMMAND DECODER	3000.	55890.	0.	0.	0.	0.	
04 00	(6)	INSTRUMENTATION	0.	7228.	0.	0.	0.	0.	
14 00 00	(5)	ORDNANCE	0.	379.	0.	0.	0.	0.	
01 00	(6)	PYROTECHNICS	0.	379.	0.	0.	0.	0.	
01	(7)	M-11 PRESSURE SQUIB	0.	83.	0.	0.	0.	0.	
02	(7)	M-69 PRESSURE SQUIB	0.	296.	0.	0.	0.	0.	
18 00 00	(5)	GROUND SUPPORT EQUIPMENT	4500.	113382.	0.	0.	294750.	5532554.	
01 00	(6)	COMMON SERVICES	2625.	46511.	0.	0.	105000.	1885525.	
02 00	(6)	CHECKOUT EQUIPMENT	0.	0.	0.	0.	70000.	1406950.	
03 00	(6)	GROUND HANDLING/SERVICING EQUIP.	0.	0.	0.	0.	84750.	1546579.	
04 00	(6)	LAUNCH MONITOR/CONTROL EQUIP.	0.	0.	0.	0.	35000.	693500.	
91 00	(6)	GSE SPARES	1875.	66872.	0.	0.	0.	0.	
91 00 00	(5)	LOGISTICS	6000.	582210.	0.	0.	0.	0.	
01 00	(6)	LOGISTICS SERVICES	3200.	57712.	0.	0.	0.	0.	
02 00	(6)	VEHICLE SPARES	2800.	524498.	0.	0.	0.	0.	
92 00 00	(5)	SYSTEMS ENGINEERING/INTEGRATION	25038.	417189.	0.	0.	757231.	12969947.	
01 00	(6)	VEHICLE SYSTEMS ANALYSIS/DESIGN	500.	9017.	0.	0.	120000.	2164200.	
02 00	(6)	VEHICLE SYSTEMS INTEGRATION	0.	0.	0.	0.	62000.	1118170.	
01	(7)	INTERFACE ANALYSIS	0.	0.	0.	0.	12000.	216420.	
02	(7)	INTERFACE EQUIPMENT DESIGN	0.	0.	0.	0.	50000.	901750.	
03 00	(6)	SYSTEMS EFFECTIVENESS	13536.	220831.	0.	0.	293948.	4839885.	
01	(7)	RELIABILITY	4000.	65620.	0.	0.	40000.	656200.	

Table 8-1 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
02	(7)	QUALITY ASSURANCE (CENTRAL)	9536.	155211.	0.	0.	228948.	3732810.	
03	(7)	HUMAN ENGINEERING	0.	0.	0.	0.	5000.	90175.	
04	(7)	TRAINING	0.	0.	0.	0.	20000.	360700.	
04 00	(6)	TEST PLANNING	1472.	26358.	0.	0.	80092.	1426199.	
05 00	(6)	ENGINEERING SERVICES	1828.	32729.	0.	0.	56950.	1019754.	
06 00	(6)	MANUFACTURING PLANS/SERVICES	7702.	128254.	0.	0.	144240.	2401740.	
93 00 00	(5)	PROGRAM MANAGEMENT	6700.	120834.	0.	0.	152000.	2741320.	
01 00	(6)	TECHNICAL DIRECTION/COORDINATION	4000.	72140.	0.	0.	75000.	1352625.	
02 00	(6)	PROGRAM CONTROL	500.	9017.	0.	0.	0.	0.	
03 00	(6)	CONFIGURATION MANAGEMENT	700.	12624.	0.	0.	19000.	342665.	
04 00	(6)	DOCUMENTATION	1500.	27052.	0.	0.	58000.	1046030.	
95 00 00	(5)	FACILITIES	5000.	83525.	0.	0.	43750.	730844.	
01 00	(6)	TEST FACILITIES	5000.	83525.	0.	0.	12500.	208812.	
02 00	(6)	LAUNCH FACILITIES	0.	0.	0.	0.	31250.	522031.	
97 00 00	(5)	TEST HARDWARE AND OPERATIONS	0.	0.	0.	0.	368105.	9550259.	
01 00	(6)	MOCKUPS	0.	0.	0.	0.	32500.	550022.	
01	(7)	AGENA TUG HARD MOCKUP	0.	0.	0.	0.	31250.	527956.	
02	(7)	AGENA/PAYLOAD SUPPORT STRUCT,MOCKU	0.	0.	0.	0.	1250.	22066.	
02 00	(6)	SUBSYSTEMS/COMPONENT LEVEL TESTING	0.	0.	0.	0.	79650.	2801433.	
01	(7)	TEST HARDWARE (DEVEL/QUAL)	0.	0.	0.	0.	18750.	1720869.	
02	(7)	TEST OPERATIONS (DEVEL/QUAL)	0.	0.	0.	0.	60900.	1080564.	
03 00	(6)	SYSTEM-LEVEL TEST HARDWARE	0.	0.	0.	0.	114135.	4122458.	
01	(7)	FLIGHT TEST ARTICLE	0.	0.	0.	0.	82935.	2857623.	
02	(7)	SYSTEMS TEST ARTICLE	0.	0.	0.	0.	17500.	953087.	
03	(7)	ORBITER INTERFACE EQUIPMENT	0.	0.	0.	0.	13700.	311748.	
04 00	(6)	SYSTEM LEVEL TEST OPERATIONS	0.	0.	0.	0.	141820.	2076345.	

Table 8-1 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
01	(7)	FLIGHT TEST OPERATIONS	0.	0.	0.	0.	93100.	1211894.	
02	(7)	CAPTIVE FIRING/COLD FLOW TEST OPS	0.	0.	0.	0.	36540.	648339.	
03	(7)	INTERFACE TEST OPERATIONS	0.	0.	0.	0.	12180.	216113.	
98 00 00	(5)	TOOLING AND SPECIAL TEST EQUIP.	2000.	33410.	0.	0.	155000.	2667485.	
01 00	(6)	TOOLING	1125.	18793.	0.	0.	100000.	1706050.	
02 00	(6)	MANUFACTURING TEST EQUIPMENT	875.	14617.	0.	0.	55000.	961435.	
99 00 00	(5)	SUPPORT	100.	169710.	0.	0.	1000.	1664913.	
01 00	(6)	TRAVEL	0.	6736.	0.	0.	0.	160483.	
02 00	(6)	REPRODUCTION	0.	10525.	0.	0.	0.	250754.	
03 00	(6)	COMPUTER	100.	53613.	0.	0.	1000.	589729.	
04 00	(6)	MATERIAL USAGE/RATED MATERIAL	0.	39049.	0.	0.	0.	149351.	
05 00	(6)	COMMON MINOR MATERIAL	0.	37192.	0.	0.	0.	91492.	
06 00	(6)	REPAIR AND MAINTENANCE	0.	22594.	0.	0.	0.	423104.	
581 00 00 00 00	(3)	SPACE SHUTTLE	0.	0.	0.	0.	82200.	1870491.	
21 00 00 00	(4)	ORBITER INTERFACE EQUIPMENT	0.	0.	0.	0.	82200.	1870491.	
01 00 00	(5)	AGENA/PAYLOAD SUPPORT STRUCTURE	0.	0.	0.	0.	37500.	768637.	
02 00 00	(5)	AGENA SERVICE PANEL	0.	0.	0.	0.	37200.	713496.	
03 00 00	(5)	SAFETY INSTRUMENTATION	0.	0.	0.	0.	0.	177750.	
04 00 00	(5)	ELECTRICAL HARNESSES	0.	0.	0.	0.	3000.	78555.	
05 00 00	(5)	DUMP LINES AND RETRACT.MECH.	0.	0.	0.	0.	4500.	132052.	
581 00 00 00 00	(3)	AGENA TUG SYSTEM LAUNCH OPS/SVCS	0.	0.	49100.	644566.	0.	0.	
01 00 00 00	(4)	AGENA LAUNCH OPERATIONS	0.	0.	49100.	644566.	0.	0.	
01 00 00	(5)	VEHICLE OPERATIONS	0.	0.	10000.	121290.	0.	0.	
02 00 00	(5)	RECEIVING/SERVICING FACIL.OPS.SUPP	0.	0.	5000.	84345.	0.	0.	
03 00 00	(5)	PAD OPERATIONS SUPPORT	0.	0.	13000.	161232.	0.	0.	
04 00 00	(5)	AGENA FACILITIES MGT/SERVICES	0.	0.	20100.	245570.	0.	0.	

Table 8-1 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
01 00	(6)	ADMINISTRATION	0.	0.	9000.	109161.	0.	0.	
02 00	(6)	SERVICES	0.	0.	11000.	135196.	0.	0.	
03 00	(6)	OTHER SUPPORT	0.	0.	100.	1213.	0.	0.	
91 00 00	(5)	LOGISTICS	0.	0.	0.	20000.	0.	0.	
01 00	(6)	PROPELLANTS/GASES	0.	0.	0.	20000.	0.	0.	
92 00 00	(5)	SYSTEMS ENGINEERING/INTEGRATION	0.	0.	1000.	12129.	0.	0.	
01 00	(6)	RELIABILITY/QA SUPPORT	0.	0.	1000.	12129.	0.	0.	
02 00	(6)	ENGINEERING SERVICES	0.	0.	0.	0.	0.	0.	
681 00 00 00 00	(3)	AGENA TUG SYSTEM FLIGHT OPS/SVCS	0.	0.	7500.	135262.	0.	0.	
01 00 00 00	(4)	MISSION PLANNING	0.	0.	3000.	54105.	0.	0.	
02 00 00 00	(4)	MISSION OPERATIONS SUPPORT	0.	0.	2000.	36070.	0.	0.	
03 00 00 00	(4)	FLIGHT DATA REDUCTION/ANALYSIS	0.	0.	2500.	45087.	0.	0.	
PROJECT TOTALS			84199.	3413541.	56600.	779829.	2006036.	40469123.	

*** NOTE -- COST FACTORS BASED ON 3 LAUNCHES PER YEAR.

8.3.1.1 Recurring Production Costs. The recurring production cost estimate of $3.41 million quoted for the baseline Agena tug is an average unit cost for the stipulated production rate of six vehicles per year.* In reference to the detailed breakout of recurring production costs (left-hand column of Table 8-1) the following important comments apply to this estimate:

a. The WBS entries for subsystem integration under each of the major subsystems refer to sustaining engineering for that particular element of the vehicle. Tasks included under this heading include design maintenance (including change engineering), and design modification/improvement.

b. Flight-to-flight mission-peculiar costs are included at a level typical of ascent Agena missions; these costs are incorporated into the totals quoted under the WBS entries for systems engineering/integration, program management, and subsystem integration.

c. The differences between an Agena tug and a typical ascent Agena as launched on Thor, Atlas or Titan show up in reduced expenditures for structures and ordnance on the Agena tug. This reflects the fact that the nose fairing, the booster adapter, the separation system, and the range safety destruct packages are all omitted from the Agena tug.

To cross-check the Agena space tug recurring-production cost estimate, an analysis was conducted to compare the historically derived recurring costs of the Gemini Agena target vehicle (GATV) with those of the tug. This reconciliation was performed in the following manner: First the total recurring costs for six GATV were averaged to get a per unit cost. These costs, in 1964 to 1966 dollars and rates, were converted to current-year dollars, with typical inflationary factors for the aerospace industry between the years 1965 to 1971 being used. The next step in the analysis was to subtract all of the costs of hardware carried on the GATV that were not applicable to the Agena space tug version. These included such items as the secondary propulsion system and the complex communications system of the GATV. It was also necessary to subtract the costs of assembling and testing the GATV. In place of these costs, appropriate values based on current Agena costs were added to represent the hardware, assembly, and test costs peculiar to the Agena space tug. Finally, the management, engineering, and support costs for the GATV were reduced in proportion to the ratio of tug hardware costs to GATV hardware costs. The calculations are summarized in Table 8-2. As indicated there the reconciled unit cost for the Agena space tug came to within $10,000 of the estimated cost. This represents a difference of a fraction of 1 percent.

*Refer to Fig. 8-2 for average unit costs at higher production rates.

Table 8-2

RECURRING PRODUCTION COST RECONCILIATION

	($ Millions)
Calculate Average GATV Unit Cost	$\frac{29.409}{6} = 4.901$
Convert to Current Dollars	4.901 x 1.4 = 6.861
Subtract Inapplicable GATV Hardware Costs	6.861 - 1.4 (1.560) = 4.677
Subtract Inapplicable GATV Assembly and Test Costs	4.677 - 1.4 (0.414) = 4.097
Subtract Proportionate Share of GATV Management, Engineering and Support Costs	4.097 - 0.47 (3.267) = 2.562
Add Agena Space Tug Peculiar Hardware/Assembly/Test Costs	2.562 + 0.677 + 0.184 = 3.423
Compare to Derived Agena Space Tug Estimate	Δ = 3.423 - 3.413 = 0.010 (~+0.3%)

For production rates beyond the nominal six per year used in this analysis, the unit production costs of the Agena tug will decline. To obtain an approximation of the magnitude of these decreases, some recent estimates of cost vs rate for ascent Agena configurations were analyzed and compared. A curve approximating the expected cost/rate relationships for the baseline Agena tug was synthesized (Fig. 8-2).

8.3.1.2 Recurring Operations Costs. Recurring operations costs for the Agena space tug vehicle are broken into two major categories: (1) launch operations and services and (2) flight operations and services.

The launch operations costs, reflecting the prelaunch sequences described elsewhere in this report, are estimated to cost approximately $646,000 for an average unit, based on a launch rate of six per year. Higher launch rates will reduce this figure. Sources of data used in deriving the recurring-operations costs included current ascent Agena

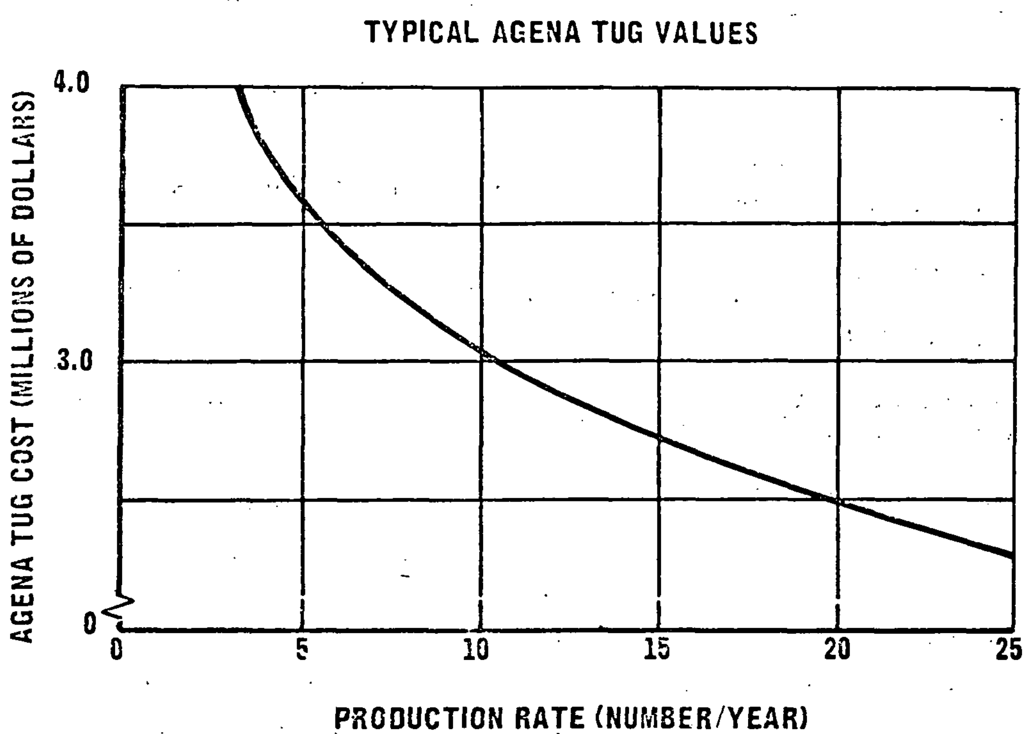

Fig. 8-2 Typical Unit Cost vs Rate Curve for Baseline Agena Tug

launch cost data as well as detailed costs on the GATV as derived under contract NAS9-10902. Where Gemini Agena manpower and cost data were used as a source, the costs were adjusted downward to account for the fact that the Agena space tug pre-launch operations would be simpler than the GATV and would require less facilities and GSE support.

In reference to the detailed breakout of Agena tug launch operations costs (in Table 8-1) (WBS entry 581-00-00-00-00 and subordinate items) the following definitions apply to the major cost categories:

a. Vehicle Operations: This entry includes the cost of crews working directly on the Agena the entire time it is at the launch base. It includes receiving inspection, checkout, handling operations (other than those performed by the shuttle crew), and Agena participation in the countdown.

b. Operations Support (581-01-02-00-00 and -03-00-00): These two entries cover the manpower required to operate Agena GSE and also any facilities that directly support Agena processing operations, such as the receiving and servicing facility (now known as the Assembly Building, Hangar E, at ETR or the pad facility. The costs exclude support of shuttle launch facilities.

c. Facilities Management and Services: This item collects costs for the overall management and administration of Agena tug facilities at the launch base. Also included under this entry are any services not provided by the other support contractors at the launch base.

The Agena tug flight operations costs were estimated to average approximately $135,000 per mission at a rate of six flights per year. These costs, which are based on an ascent mission of less than 1-day duration, include the generation of a mission plan, Lockheed participation in mission control activities, and post-flight data interpretation.

The total of average unit recurring-operations costs (sum of the center column in Table 8-1) was estimated to be approximately $781,000 based on the reference launch rate.

8.3.1.3 Nonrecurring Costs. It is estimated that the nonrecurring costs for the baseline Agena space tug vehicle and its supporting equipment will total approximately $40.5 million. This analysis is based on the development and qualification plans for the Agena space tug as outlined in Volume II, Part 3 of this report. The methodology used in deriving the estimate was generally similar to that for the recurring costs; however, special

emphasis was placed on identifying the major tasks, the major test hardware and operations, and the shuttle interface equipment required to bring the Agena space tug to an operational status. Peak annual funding required during the development phase (nonrecurring costs) is $16 million.

The Agena tug nonrecurring costs comprise two elements:

Research, Development, Test, and Evaluation (RDT&E) for Agena Tug	$38.6 million
Fabrication of Orbiter Interface Equipment	$ 1.9 million
	$40.5 million

In respect to the Agena space tug RDT&E costs (WBS entry 181-00-00-00-00 nonrecurring costs in Table 8-1), the subsystems development costs are relatively low; this reflects the fact that the Agena space tug requires rather few new items of hardware. The systems engineering and integration costs are fairly high, because systems integration, particularly integration of the Agena with the shuttle, requires considerable analysis and documentation. For example, reliability and quality functions must take into account the necessity to operate inside the cargo bay of the manned space shuttle vehicle. Engineering and manufacturing support services must generate new drawings and procedures. Engineering analyses must also reflect the change from expendable launch vehicles to the space shuttle. Test plans must be written to cover shuttle-peculiar tests. The line item of systems engineering and integration also includes the design (but not the fabrication) of the shuttle orbiter interface equipment.

Particular points of clarification for detailed RDT&E cost entries in the WBS are as follows:

a. The subsystem integration costs shown for most of the Agena tug subsystems represent expenditures for initial design of the overall subsystem to meet the tug requirements, and also for the design of any new components peculiar to the Agena tug configuration (e.g., propellant dump system hardware).

b. The WBS entries for flight test hardware and operations refer to what is also designated as a deployment test in the development plan.

Fabrication costs for six sets (five flight + one backup) of shuttle interface equipment to enable the Agena tug to be operated from the orbiter cargo bay are presented under

WBS entry number 381-00-00-00-00 in Table 8-1. Since there is no precise analogy for hardware of this type, the quoted nonrecurring costs of $1.87 million represent a higher uncertainty than any other costs in the Agena tug system.

In the same way that the recurring costs were reconciled against the GATV unit costs, an analysis was conducted to compare the nonrecurring costs of the Agena space tug to those of the GATV. Very briefly, the approach used in this reconciliation started with conversion of the nonrecurring costs of the GATV to 1971 dollars. Then the costs for subsystems developments made under the GATV program, such as the Model 8247 engine and the Model 8250 secondary propulsion system, were subtracted from this total. After GATV subsystem developments were removed the tug subsystem development costs were added back. The costs for design and fabrication of the Shuttle interface equipment were also added in, as were the costs for the single flight test of the Agena Space Tug (there was no comparable flight test of the GATV). Results of this analysis are presented in Table 8-3. The difference between this reconciled estimate and the derived estimate for the Agena space tug amounts to approximately $1.7 million, or roughly 4 percent. This appears to be a reasonable correlation.

Table 8-3
NONRECURRING COST RECONCILIATION

	($ Millions)
Calculate GATV Nonrecurring Cost in Current Dollars	52.741 x 1.4 = 73.837
Subtract Inapplicable Subsystem Developments (e.g., Propulsion, TT&C) and Services	73.837 - 43.284 = 30.553
Add Tug Subsystem Development	30.553 + 4.757 = 35.310
Add Shuttle Interface Equipment Design and Fabrication	35.310 + 2.772 = 38.082
Add Flight Test Hardware and Operations	38.082 + 4.070 = 42.125
Compared to Derived Agena Tug Estimate	Δ = 42.125 - 40.469 = 1.683 (~ +4%)

8.3.2 Evolutionary Agena Tug Costs

The costs associated with an evolutionary Agena space tug were derived by the same methodology as that used for the baseline version of the Agena tug. (The evolutionary Agena tug is described in Section 5 of this volume.) The results of this cost analysis are summarized in a direct computer printout of the indentured costs by WBS level, as computed in the DBANK program (Table 8-4). The evolutionary Agena tug recurring and nonrecurring costs presented in this table are discussed at greater length in the following sections.

8.3.2.1 Recurring Production Costs. The estimated recurring-production costs for the evolutionary Agena tug are $3.86 million per average unit at a six-per-year rate. Although this amounts to an increase of approximately $560,000 over the baseline version, the latter figure represents the absolute maximum difference between the two configurations; it is anticipated that more refined analysis will narrow this difference appreciably.

Principal differences in hardware costs between the evolutionary Agena tug and the baseline version occur in the structures cost. This includes the cost for a larger propellant tank and a larger forward equipment rack. Electrical power system costs differ by virtue of the increased amount of wire harness required on the evolutionary Agena tug. Other cost differences between the evolutionary Agena space tug and the baseline version are in subsystems installation and checkout (predominantly final assembly), sustaining engineering/program management, and GSE and facilities maintenance costs.

Details of the evolutionary Agena tug recurring production costs are presented in the left-hand column of Table 8-4.

Table 8-4

EVOLUTIONARY AGENA SPACE TUG COST SUMMARY

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO:	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
01 00 00	(5)	STRUCTURES	0.	0.	0.	0.	0.	0.	
181 00 00 00 00	(3)	AGENA SPACE TUG SYSTEM	13625.	266645.	0.	0.	75000.	1352625.	
01 00 00 00	(4)	AGENA SPACE TUG STAGE	13625.	266645.	0.	0.	75000.	1352625.	
01 00	(6)	SUBSYSTEM INTEGRATION	2000.	36070.	0.	0.	75000.	1352625.	
02 00	(6)	FORWARD SECTION	3125.	69978.	0.	0.	0.	0.	
03 00	(6)	PROPELLANT TANK ASSEMBLY	5625.	105816.	0.	0.	0.	0.	
04 00	(6)	AFT SECTION	1250.	25621.	0.	0.	0.	0.	
05 00	(6)	ATTACHMENT RING	500.	9537.	0.	0.	0.	0.	
06 00	(6)	MISCELLANEOUS STRUCTURES	1125.	19623.	0.	C.	0.	0.	
02 00 00	(5)	SUBSYSTEMS INSTALLATION/CHECKOUT	15609.	271251.	0.	0.	0.	0.	
01 00	(6)	FINAL ASSEMBLY AND INSPECTION	5000.	83525.	0.	0.	0.	0.	
02 00	(6)	POST-ACCEPTANCE PROCESSING	500.	8352.	0.	0.	0.	0.	
03 00	(6)	ACCEPTANCE TESTING	10109.	179374.	0.	0.	0.	0.	
01	(7)	AMBIENT FUNCTIONAL TEST	7308.	129668.	0.	0.	0.	0.	
02	(7)	THERMAL/VACUUM TEST	2801.	49706.	0.	0.	0.	0.	
03 00 00	(5)	PROPULSION	1556.	620797.	0.	0.	45000.	811575.	
01 00	(6)	SUBSYSTEM INTEGRATION	1000.	18035.	0.	0.	45000.	811575.	
02 00	(6)	PRIMARY PROPULSION SYSTEM	556.	602762.	0.	0.	0.	0.	
01	(7)	MODEL 8247 ENGINE	0.	535600.	0.	0.	0.	0.	
02	(7)	PROPELLANT ISOLATION VALVES (2)	0.	14220.	0.	0.	0.	0.	
03	(7)	PROPELLANT DUMP VALVES (2)	0.	11850.	0.	0.	0.	0.	
04	(7)	PROPELLANT FILL COUPLINGS (2)	0.	829.	0.	0.	0.	0.	
05	(7)	PROPELLANT VENT COUPLINGS (2)	150.	2541.	0.	0.	0.	0.	
06	(7)	PROPELLANT LINES/PLUMBING INTEGRAT	250.	7968.	0.	0.	0.	0.	
07	(7)	FAST SHUTDOWN KIT	125.	2207.	0.	0.	0.	0.	
08	(7)	HELIUM SUPPLY SPHERE	0.	11850.	0.	0.	0.	0.	

Table 8-4 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
09	(7)	HELIUM PRESSURE REGULATOR	0.	11850.	0.	0.	0.	0.	
10	(7)	HELIUM FILL COUPLING	31.	528.	0.	0.	0.	0.	
11	(7)	PYRO HELIUM CONTROL VALVE	0.	3318.	0.	0.	0.	0.	
05 00 00	(5)	ELECTRICAL POWER	5420.	129589.	0.	0.	15000.	270525.	
01 00	(6)	SUBSYSTEM INTEGRATION	1800.	32463.	0.	0.	15000.	270525.	
02 00	(6)	POWER SUPPLY SYSTEM	0.	10072.	0.	0.	0.	0.	
01	(7)	PRIMARY BATTERIES TYPE IV-B	0.	2962.	0.	0.	0.	0.	
02	(7)	PRIMARY BATTERY,TYPE I-H *	0.	7110.	0.	0.	0.	0.	
03	(7)	SECONDARY BATTERY,TYPE VI-A **	0.	0.	0.	0.	0.	0.	
04	(7)	SOLAR ARRAY **	0.	0.	0.	0.	0.	0.	
05	(7)	CHARGE CONTROLLER **	0.	0.	0.	0.	0.	0.	
03 00	(6)	POWER DISTRIBUTION SYSTEM	3620.	87054.	0.	0.	0.	0.	
01	(7)	POWER DISTRIBUTION J-BOX	385.	10087.	0.	0.	0.	0.	
02	(7)	AFT CONTROL/INSTRUMENTATION J-BOX	392.	8310.	0.	0.	0.	0.	
03	(7)	PYROTECHNIC CONTROL J-BOX	592.	10925.	0.	0.	0.	0.	
04	(7)	ELECTRICAL HARNESSING	2250.	57731.	0.	0.	0.	0.	
10 00 00	(5)	GUIDANCE AND CONTROL	3361.	627957.	0.	0.	21000.	378735.	
01 00	(6)	SUBSYSTEM INTEGRATION	1200.	21642.	0.	0.	21000.	378735.	
02 00	(6)	GUIDANCE SYSTEM	325.	510248.	0.	0.	0.	0.	
01	(7)	INERTIAL SENSOR ASSEMBLY	0.	288400.	0.	0.	0.	0.	
02	(7)	COMPUTER	0.	216300.	0.	0.	0.	0.	
03	(7)	GUIDANCE MODULE	325.	5548.	0.	0.	0.	0.	
03 00	(6)	FLIGHT CONTROLS SYSTEM	1805.	40674.	0.	0.	0.	0.	
01	(7)	FLIGHT CONTROL ELECTRONICS PKG	1805.	40674.	0.	0.	0.	0.	
04 00	(6)	STABILIZATION CONTROL SYSTEM **	0.	0.	0.	0.	0.	0.	
01	(7)	HORIZON SENSOR ASSEMBLIES (2) **	0.	0.	0.	0.	0.	0.	

*Mission-peculiar to synchronous equatorial mission
**Mission-peculiar to 30-day low earth orbit mission

Table 8-4 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
~~02~~	~~(7)~~	~~GYRO REFERENCE ASSEMBLIES (2) **~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	0.	
03	(7)	ORBIT ELECTRONICS ASSEMBLY **	0.	0.	0.	0.	0.	0.	
04	(7)	AUGMENTED ELECTRONICS ASSEMBLY **	0.	0.	0.	0.	0.	0.	
~~05~~	~~(7)~~	~~DACS MODULE **~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	0.	
05 00	(6)	HYDRAULIC SYSTEM	0.	19315.	0.	0.	0.	0.	
01	(7)	HYDRAULIC POWER PACKAGE	0.	10783.	0.	0.	0.	0.	
~~02~~	~~(7)~~	~~HYDRAULIC ACTUATORS (2)~~	~~0.~~	~~8532.~~	~~0.~~	~~0.~~	~~0.~~	0.	
06 00	(6)	REACTION CONTROL SYSTEM	31.	36078.	0.	0.	0.	0.	
01	(7)	NITROGEN SUPPLY SPHERE	0.	5214.	0.	0.	0.	0.	
~~02~~	~~(7)~~	~~NITROGEN PRESSURE REGULATOR~~	~~0.~~	~~17775.~~	~~0.~~	~~0.~~	~~0.~~	0.	
03	(7)	NITROGEN THRUSTERS (2)	0.	12561.	0.	0.	0.	0.	
04	(7)	NITROGEN FILL COUPLING	31.	528.	0.	0.	0.	0.	
~~05~~	~~(7)~~	~~DACS NITROGEN SPHERE **~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	0.	
06	(7)	DACS NITROGEN REGULATOR **	0.	0.	0.	0.	0.	0.	
07	(7)	DACS NITROGEN THRUSTERS (2) **	0.	0.	0.	0.	0.	0.	
~~08~~	~~(7)~~	~~DACS NITROGEN PLUMBING **~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	~~0.~~	0.	
13 00 00	(5)	TELEMETRY,TRACKING AND COMMAND	7415.	223652.	0.	0.	63000.	1136205.	
01 00	(6)	SUBSYSTEM INTEGRATION	3500.	63122.	0.	0.	63000.	1136205.	
~~02 00~~	~~(6)~~	~~TELEMETRY/TRACKING SYSTEM~~	~~915.~~	~~76199.~~	~~0.~~	~~0.~~	~~0.~~	0.	
01	(7)	PCM TELEMETRY MODULE,TYPE IV	0.	9835.	0.	0.	0.	0.	
02	(7)	BASEBAND ASSEMBLY	0.	14220.	0.	0.	0.	0.	
~~03~~	~~(7)~~	~~UHF TRANSMITTER,2-WATT~~	~~0.~~	~~17775.~~	~~0.~~	~~0.~~	~~0.~~	0.	
04	(7)	POWER AMPLIFIER *	0.	5925.	0.	0.	0.	0.	
05	(7)	MULTICOUPLER,TYPE 14	0.	3199.	0.	0.	0.	0.	
~~06~~	~~(7)~~	~~RF SWITCH,TYPE 14~~	~~0.~~	~~6991.~~	~~0.~~	~~0.~~	~~0.~~	0.	
07	(7)	ANTENNA,TYPE 28	72.	1256.	0.	0.	0.	0.	

Table 8-4 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
08	(7)	ANTENNA,PARABOLIC *	300.	5233.	0.	0.	0.	0.	
09	(7)	TELEMETRY J-BOX	542.	11764.	0.	0.	0.	0.	
03 00	(6)	COMMAND SYSTEM	3000.	73665.	0.	0.	0.	0.	
01	(7)	COMMAND RECEIVER/DEMODULATOR	0.	17775.	0.	0.	0.	0.	
02	(7)	COMMAND DECODER	3000.	55890.	0.	0.	0.	0.	
04 00	(6)	INSTRUMENTATION	0.	10665.	0.	0.	0.	0.	
14 00 00	(5)	ORDNANCE	0.	379.	0.	0.	0.	0.	
01 00	(6)	PYROTECHNICS	0.	379.	0.	0.	0.	0.	
01	(7)	M-11 PRESSURE SQUIB	0.	83.	0.	0.	0.	0.	
02	(7)	M-69 PRESSURE SQUIB	0.	296.	0.	0.	0.	0.	
15 00 00	(5)	GROUND SUPPORT EQUIPMENT	5125.	124488.	0.	0.	329250.	6328081.	
01 00	(6)	COMMON SERVICES	3250.	57616.	0.	0.	92000.	1655960.	
02 00	(6)	CHECKOUT EQUIPMENT	0.	0.	0.	0.	81250.	1637081.	
03 00	(6)	GROUND HANDLING/SERVICING EQUIP.	0.	0.	0.	0.	118750.	2299069.	
04 00	(6)	LAUNCH MONITOR/CONTROL EQUIP.	0.	0.	0.	0.	37250.	735971.	
91 00	(6)	GSE SPARES	1875.	66872.	0.	0.	0.	0.	
91 00 00	(5)	LOGISTICS	6000.	629610.	0.	0.	0.	0.	
01 00	(6)	LOGISTICS SERVICES	3200.	57712.	0.	0.	0.	0.	
02 00	(6)	VEHICLE SPARES	2800.	571898.	0.	0.	0.	0.	
92 00 00	(5)	SYSTEMS ENGINEERING/INTEGRATION	30933.	515138.	0.	0.	884983.	15180967.	
01 00	(6)	VEHICLE SYSTEMS ANALYSIS/DESIGN	500.	9017.	0.	0.	160000.	2885600.	
02 00	(6)	VEHICLE SYSTEMS INTEGRATION	0.	0.	0.	0.	65000.	1172275.	
01	(7)	INTERFACE ANALYSIS	0.	0.	0.	0.	15000.	270525.	
02	(7)	INTERFACE EQUIPMENT DESIGN	0.	0.	0.	0.	50000.	901750.	
03 00	(6)	SYSTEMS EFFECTIVENESS	15638.	255032.	0.	0.	328989.	5416772.	
01	(7)	RELIABILITY	4000.	65620.	0.	0.	45000.	738225.	

Table 8-4 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
02	(7)	QUALITY ASSURANCE (CENTRAL)	11638.	189412.	0.	0.	255989.	4173567.	
03	(7)	HUMAN ENGINEERING	0.	0.	0.	0.	6000.	108210.	
04	(7)	TRAINING	0.	0.	0.	0.	22000.	396770.	
04 00	(6)	TEST PLANNING	1909.	34183.	0.	0.	90759.	1616211.	
05 00	(6)	ENGINEERING SERVICES	1865.	33391.	0.	0.	71676.	1283438.	
06 00	(6)	MANUFACTURING PLANS/SERVICES	11021.	183515.	0.	0.	168559.	2806672.	
93 00 00	(5)	PROGRAM MANAGEMENT	6700.	120834.	0.	0.	185000.	3336475.	
01 00	(6)	TECHNICAL DIRECTION/COORDINATION	4000.	72140.	0.	0.	90000.	1623150.	
02 00	(6)	PROGRAM CONTROL	500.	9017.	0.	0.	0.	0.	
03 00	(6)	CONFIGURATION MANAGEMENT	700.	12624.	0.	0.	30000.	541050.	
04 00	(6)	DOCUMENTATION	1500.	27052.	0.	0.	65000.	1172275.	
95 00 00	(5)	FACILITIES	5000.	83525.	0.	0.	43750.	730844.	
01 00	(6)	TEST FACILITIES	5000.	83525.	0.	0.	12500.	208812.	
02 00	(6)	LAUNCH FACILITIES	0.	0.	0.	0.	31250.	522031.	
97 00 00	(5)	TEST HARDWARE AND OPERATIONS	0.	0.	0.	0.	425966.	10663496.	
01 00	(6)	MOCKUPS	0.	0.	0.	0.	41250.	755316.	
01	(7)	AGENA TUG HARD MOCKUP	0.	0.	0.	0.	40000.	733250.	
02	(7)	AGENA/PAYLOAD SUPPORT STRUCT,MOCKU	0.	0.	0.	0.	1250.	22066.	
02 00	(6)	SUBSYSTEMS/COMPONENT LEVEL TESTING	0.	0.	0.	0.	98080.	3140853.	
01	(7)	TEST HARDWARE (DEVEL/QUAL)	0.	0.	0.	0.	25000.	1844176.	
02	(7)	TEST OPERATIONS (DEVEL/QUAL)	0.	0.	0.	0.	73080.	1296677.	
03 00	(6)	SYSTEM-LEVEL TEST HARDWARE	0.	0.	0.	0.	139262.	4603103.	
01	(7)	FLIGHT TEST ARTICLE	0.	0.	0.	0.	98812.	3164180.	
02	(7)	SYSTEMS TEST ARTICLE	0.	0.	0.	0.	26750.	1127174.	
03	(7)	ORBITER INTERFACE EQUIPMENT	0.	0.	0.	0.	13700.	311748.	
04 00	(6)	SYSTEM LEVEL TEST OPERATIONS	0.	0.	0.	0.	147374.	2164224.	

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
01	(7)	FLIGHT TEST OPERATIONS	0.	0.	0.	0.	95000.	1234939.	
02	(7)	CAPTIVE FIRING/COLD FLOW TEST OPS	0.	0.	0.	0.	40194.	713173.	
03	(7)	INTERFACE TEST OPERATIONS	0.	0.	0.	0.	12180.	216113.	
98 00 00	(5)	TOOLING AND SPECIAL TEST EQUIP.	3125.	52203.	0.	0.	213750.	3736594.	
01 00	(6)	TOOLING	2250.	37586.	0.	0.	156250.	2728656.	
02 00	(6)	MANUFACTURING TEST EQUIPMENT	875.	14617.	0.	0.	57500.	1007937.	
99 00 00	(5)	SUPPORT	100.	192287.	0.	0.	1000.	1865294.	
01 00	(6)	TRAVEL	0.	8318.	0.	0.	0.	190792.	
02 00	(6)	REPRODUCTION	0.	12996.	0.	0.	0.	298112.	
03 00	(6)	COMPUTER	100.	53613.	0.	0.	1000.	589729.	
04 00	(6)	MATERIAL USAGE/RATED MATERIAL	0.	43463.	0.	0.	0.	182521.	
05 00	(6)	COMMON MINOR MATERIAL	0.	41569.	0.	0.	0.	109701.	
06 00	(6)	REPAIR AND MAINTENANCE	0.	32329.	0.	0.	0.	494439.	
381 00 00 00 00	(3)	SPACE SHUTTLE	0.	0.	0.	0.	82200.	1870491.	
21 00 00 00	(4)	ORBITER INTERFACE EQUIPMENT	0.	0.	0.	0.	82200.	1870491.	
01 00 00	(5)	AGENA/PAYLOAD SUPPORT STRUCTURE	0.	0.	0.	0.	37500.	768637.	
02 00 00	(5)	AGENA SERVICE PANEL	0.	0.	0.	0.	37200.	713496.	
03 00 00	(5)	SAFETY INSTRUMENTATION	0.	0.	0.	0.	0.	177750.	
04 00 00	(5)	ELECTRICAL HARNESSES	0.	0.	0.	0.	3000.	78555.	
05 00 00	(5)	DUMP LINES AND RETRACT.MECH.	0.	0.	0.	0.	4500.	132052.	
581 00 00 00 00	(3)	AGENA TUG SYSTEM LAUNCH OPS/SVCS	0.	0.	51100.	708824.	0.	0.	
01 00 00 00	(4)	AGENA LAUNCH OPERATIONS	0.	0.	51100.	708824.	0.	0.	
01 00 00	(5)	VEHICLE OPERATIONS	0.	0.	12000.	145548.	0.	0.	
02 00 00	(5)	RECEIVING/SERVICING FACIL.OPS.SUPP	0.	0.	5000.	84345.	0.	0.	
03 00 00	(5)	PAD OPERATIONS SUPPORT	0.	0.	13000.	161232.	0.	0.	
04 00 00	(5)	AGENA FACILITIES MGT/SERVICES	0.	0.	20100.	245570.	0.	0.	

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Table 8-4 (Cont)

TOTAL PROGRAM COSTS BY WBS ELEMENT

WBS NO.	LEVEL	WBS IDENTIFICATION	RECURRING PROD HRS	RECURRING PROD $	RECURRING OPER HRS	RECURRING OPER $	NONRECURRING HRS	NONRECURRING $	COMMENTS
01 00	(6)	ADMINISTRATION	0.	0.	9000.	109161.	0.	0.	
02 00	(6)	SERVICES	0.	0.	11000.	135196.	0.	0.	
03 00	(6)	OTHER SUPPORT	0.	0.	100.	1213.	0.	0.	
91 00 00	(5)	LOGISTICS	0.	0.	0.	60000.	0.	0.	
01 00	(6)	PROPELLANTS/GASES	0.	0.	0.	60000.	0.	0.	
92 00 00	(5)	SYSTEMS ENGINEERING/INTEGRATION	0.	0.	1000.	12129.	0.	0.	
01 00	(6)	RELIABILITY/QA SUPPORT	0.	0.	1000.	12129.	0.	0.	
02 00	(6)	ENGINEERING SERVICES	0.	0.	0.	0.	0.	0.	
681 00 00 00 00	(3)	AGENA TUG SYSTEM FLIGHT OPS/SVCS	0.	0.	7500.	135262.	0.	0.	
01 00 00 00	(4)	MISSION PLANNING	0.	0.	3000.	54105.	0.	0.	
02 00 00 00	(4)	MISSION OPERATIONS SUPPORT	0.	0.	2000.	36070.	0.	0.	
03 00 00 00	(4)	FLIGHT DATA REDUCTION/ANALYSIS	0.	0.	2500.	45087.	0.	0.	
PROJECT TOTALS			103969.	3858355.	58600.	844087.	2384899.	47661896.	

*** NOTE -- COST FACTORS BASED ON 6 LAUNCHES PER YEAR.

8.3.2.2 Recurring Operations Costs. The evolutionary Agena space tug recurring operations costs of $845,000 per average unit differ by only about $60,000 from the operations costs of the baseline Agena tug vehicle. The cost differences occur in launch operations; specifically, the differences are in the vehicle servicing operations required for the larger evolutionary Agena vehicle and in the cost of propellants. There are no differences in flight operations and services costs between the evolutionary Agena space tug and the baseline Agena tug.

8.3.2.3 Nonrecurring Costs. The evolutionary Agena space tug nonrecurring costs were based on the assumption that development of a tug version of Agena proceeds directly to this larger configuration and does not evolve from the baseline (5-feet diameter) tug. Under these assumptions the estimated nonrecurring cost for the evolutionary Agena tug was $47.7 million. This increase of $7.2 million over the baseline configuration reflects those relatively small costs required to increase the diameter of the Agena vehicle and to upgrade its propulsion system to a specific impulse of 310 seconds. WBS entries principally affected by the incorporation of the evolutionary Agena space tug include structures, tooling, GSE, and systems engineering and management. Specific cost items covered include the design of a large propellant tank and forward rack; the design and fabrication of the tooling necessary to build these items and to assemble the increased size vehicle; the cost of ground support equipment to service and handle the vehicle; and costs for documenting and analyzing the new configuration.

Details of the evolutionary Agena tug nonrecurring costs are presented in the right-hand column of Table 8-4.

8.3.3 Extended-Mission Version of Agena Tug

To obtain an estimate of the Agena space tug costs for incorporating the capability to perform a low earth orbit mission (in which the Agena space tug serves also to support a payload for 30 days in orbit) a brief analysis was completed. The costs derived for this version of the Agena space tug were estimated through use of less rigorous techniques than the ascent versions of the Agena space tug. Costs were estimated by analogies to current versions of the Agena in which integrated spacecraft functions

are performed. These costing techniques were used to reach an estimate that the unit recurring-production cost of an Agena space tug configured for the low earth orbit mission might be approximately $4.98 million and the recurring operations costs approximately $1.2 million. These represent increases of $1.6 million and $0.4 million over the baseline tug costs. The nonrecurring costs are estimated at approximately $44.8 million, which is an increase of $4.3 million over the baseline configuration.

Further refinement of these costs, and a detailed analysis of their economic implications in terms of total program expenditures (payloads plus transportation) should be a high-priority effort for follow-on studies.

Section 9

TANDEM CONFIGURATIONS

Section 9
TANDEM CONFIGURATIONS

9.1 CONFIGURATION DEFINITION

A brief preliminary analysis was made of the potential use of a tandem Agena space tug configuration. In this case, two Agena space tugs are mounted together to form a two-stage vehicle, the top stage being a normal Agena tug as discussed previously, while the lower stage has been stripped of all equipment not needed to perform the mission. The guidance function, the telemetry and communication, and the electrical power supply are thus provided by the top stage (the "smart" stage), and the lower stage is only a velocity package (the "dumb" stage), consisting of the tank section, the propulsion system, the required structure, and the attitude control thrusters. The two stages are connected by a truss-type adapter structure, and the vehicles are both tanked to design capacity within the weight limitations determined by the shuttle payload capability.

Three different vehicle configurations considered for this analysis are shown in Table 9-1. The configurations are composed of standard Agena tugs and evolutionary Agena tug vehicles.

Table 9-1

TANDEM CONFIGURATIONS

	Configuration 1	Configuration 2	Configuration 3
Stage 1	Agena Tug 5-Ft Diameter, Stripped	Evolutionary Agena Tug 10-Ft Diameter, Stripped	Evolutionary Agena Tug 10-Ft Diameter, Stripped
Stage 2	Agena Tug 5-Ft Diameter	Evolutionary Agena Tug 10-Ft Diameter	Agena Tug 5-Ft Diameter

9.1.1 Agena Space Tug Tandem Configuration

Figure 9-1 shows a preliminary design of Configuration 1, consisting of two Agena space tug vehicles. The two stages will be mated with the payload attached to the forward Agena and launched in this configuration. The total weight of this configuration is 30,537 pounds; it can therefore be launched on one shuttle flight, as indicated in Fig. 9-2a. The length of the two-stage vehicle is 42 feet, which leaves 18 feet of cargo bay volume available for the payload. Although the two stages are joined at launch, each stage is supported by a single cradle. The interstage structure is designed to carry only the engine thrust loads during the aft stage burning. This reduces the structural weight of the interstage, which is made of 2021 aluminum alloy tubing, has a diameter of 60 inches, and is 122 inches long. The aft end of the interstage is volted to the payload support ring of the first stage. The forward end of the interstage is joined to a tab added to the aft support ring of the second stage; the separation joint is an integral part of this joint. The two stages are separated by Super*Zip, a pyrotechnic linear-shaped charge, which has been qualified by LMSC and is being flown on LMSC 5-, 10-, and 14-foot diameter shrouds. Following separation of the two stages the interstage truss is jettisoned, along with the first stage; only the forward half of the retaining doublers remains attached to the forward stage. The total weight of the interstage truss is 95 pounds, of which 88 pounds is jettisoned at separation. The dry weight of the top stage Agena tug is 1,369 pounds, the dry weight of the first stage Agena is 1,043 pounds, and the total launch weight – including support structure and equipment – is 32,057 pounds with the tanks fully loaded.

9.1.2 Evolutionary Agena Tug Tandem Configuration

Figure 9-3 shows a preliminary design of Configuration 2, consisting of two evolutionary 10-foot-diameter Agena tug vehicles. The operational procedure of this arrangement is that the forward stage, which is completely operational, is launched with the payload attached, and deployed on a given orbit; it is then stored on-orbit in deactivated mode until the aft stage is launched on a second shuttle flight, and the two stages are joined after rendezvous in the parking orbit, as indicated in Fig. 9-2b. This procedure is

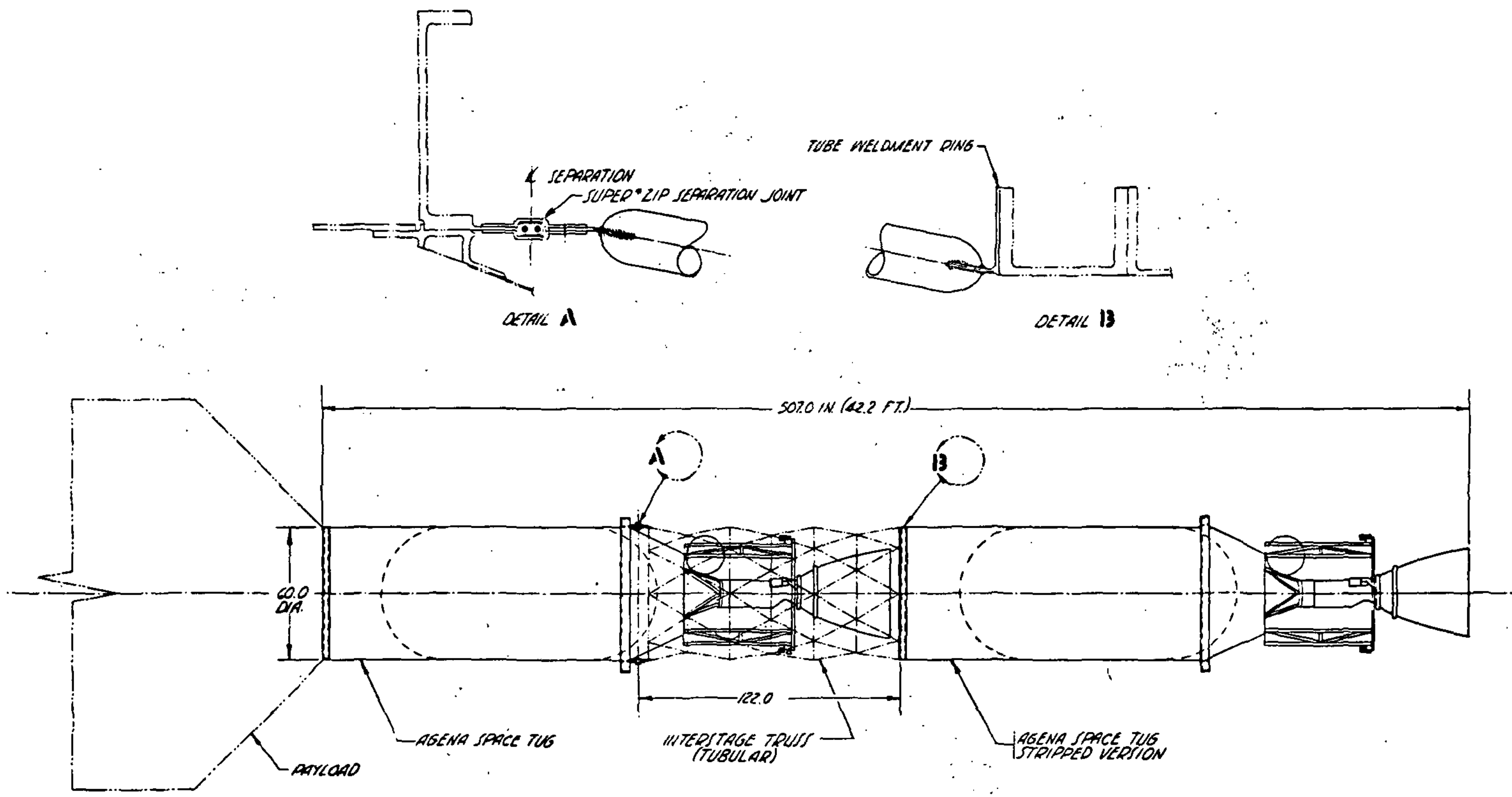
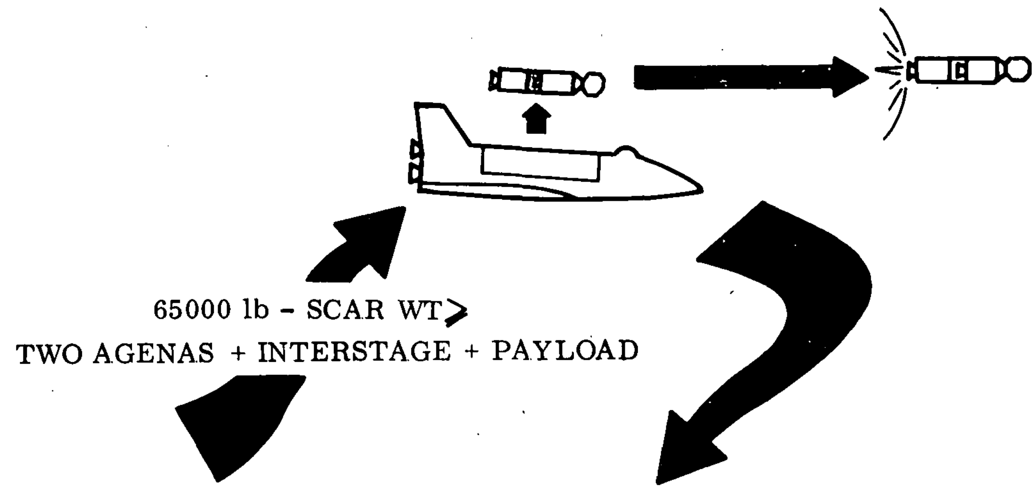
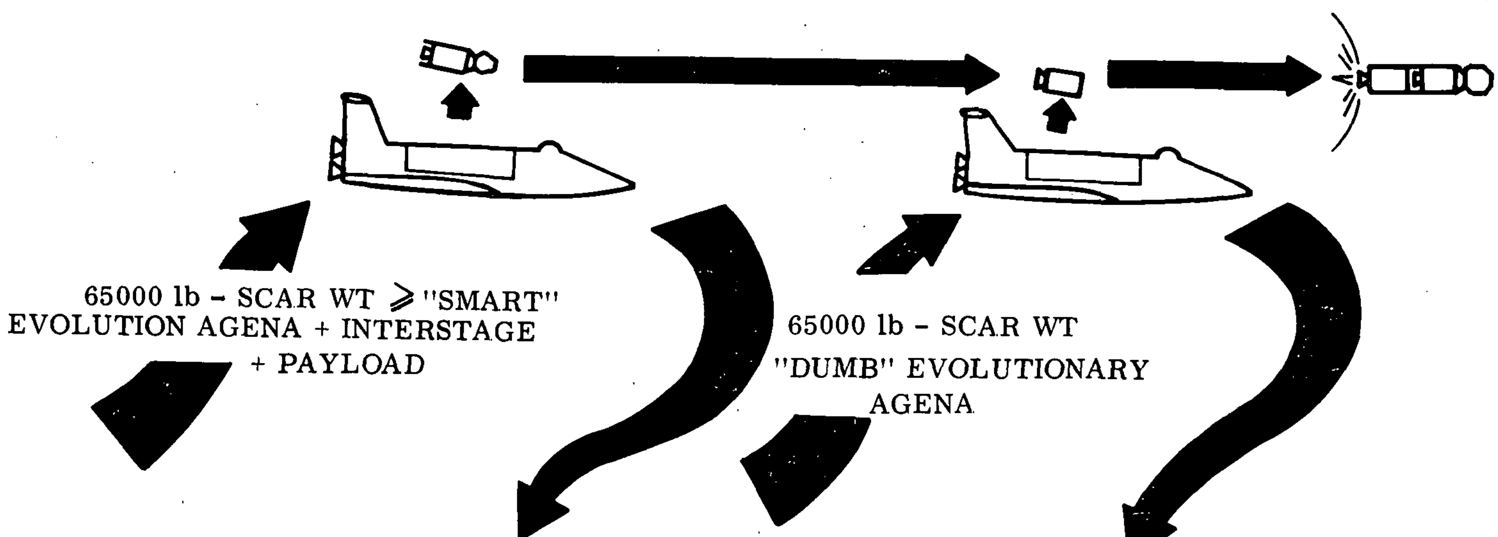


Fig. 9-1 Agena Space Tug Tandem Launched



a. Two 5-Foot Diameter Agena Tugs



Two 10-Foot Diameter Evolutionary Agenas or a 5-Foot "Smart" and 10-Foot Diameter "Dumb" Agena Combination

Fig. 9-2 Tandem-Stage Space Shuttle Support

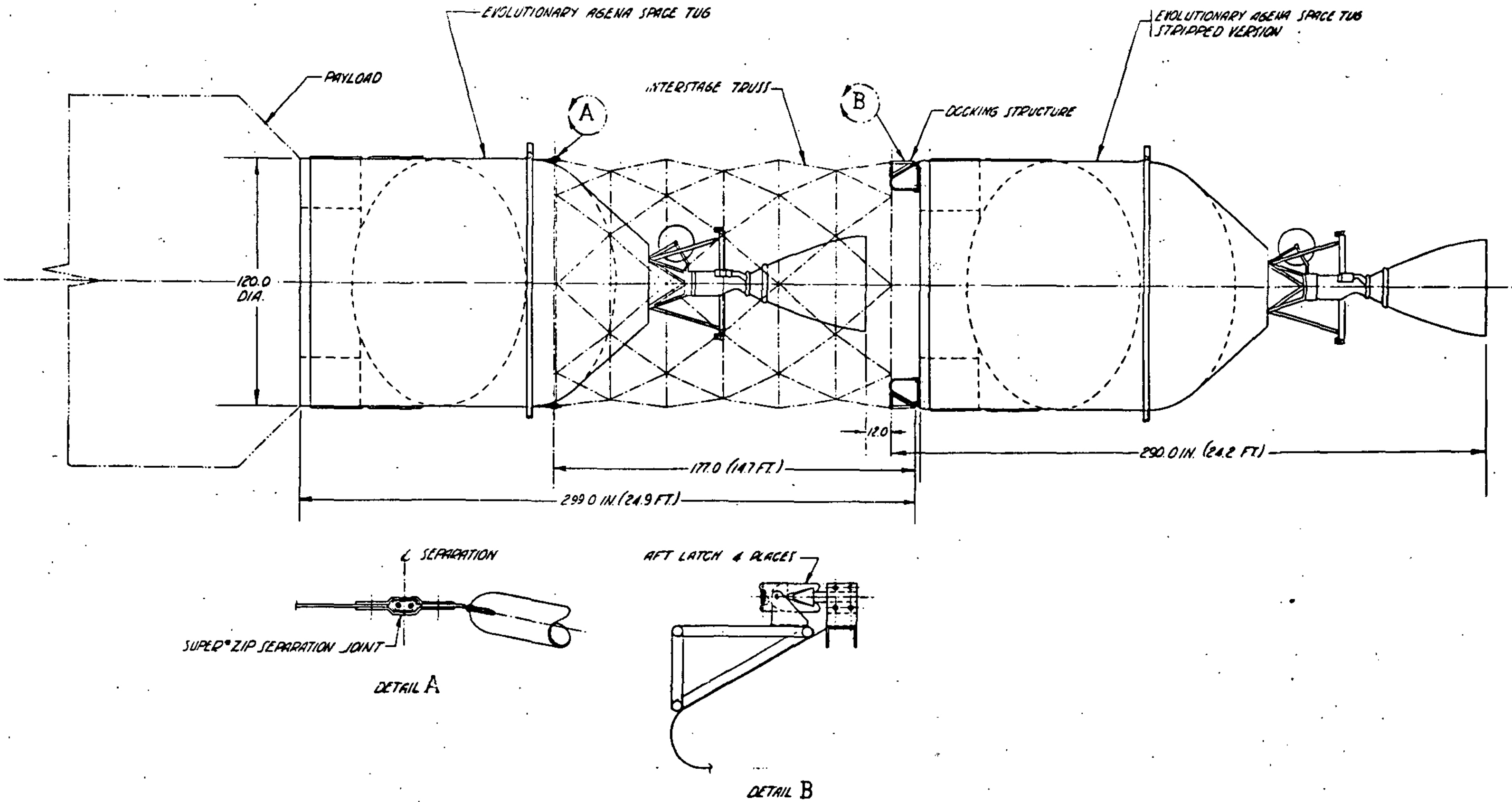


Fig. 9-3 Evolutionary Agena Space Tug Tandem Docking

dictated by the shuttle payload weight capability. The interstage structure will be launched with the forward stage attached to its aft tank skirt. In this case the attachment structure also incorporates the Super* Zip pyrotechnic linear shaped charge for separation. The first stage is again stripped for all redundant subsystem and equipment.

The two stages are mated and docked at the forward end of the first stage, which has a conical sheet metal structure. A similarly shaped receiver is installed at the rear of the interstage adapter. Thrust loads from the aft stage will then be reacted radially to the receiver. A latching assembly at four places prevents demating of the stages.

The total launch weight of the top-stage Agena is 54,120 pounds, including the support equipment, if the tanks are fully loaded. The total launch weight of the aft Agena is 50,260 pounds, and the forward Agena is 51,362 pounds, including support equipment. The total weight of the tubular truss interstage structure is 170 pounds, of which 139 pounds are jettisoned at separation. The dry weight of the top stage is 1894 pounds and the lower stage is 1406 pounds.

The third concept, Configuration 3, is a combination of the previous two, using a 5-foot-diameter Agena tug as the top stage and a 10-foot-diameter evolutionary Agena tug as the lower stage. The interstage structure is a 60-inch-diameter tubular truss similar to that shown in Configuration 1. This configuration must also be launched on two shuttle flights.

9.2 PERFORMANCE CAPABILITY

The payload-carrying capability of tandem Agena configurations demonstrates the flexibility and the wide range of mission support that these earth-storagle propellant configurations can supply. The payload capability of the three configurations discussed in par. 9.1 was evaluated for a propellant combination of UDMH/HDA delivering a specific impulse of 310 seconds. Figure 9-4 illustrates the operational profiles flight

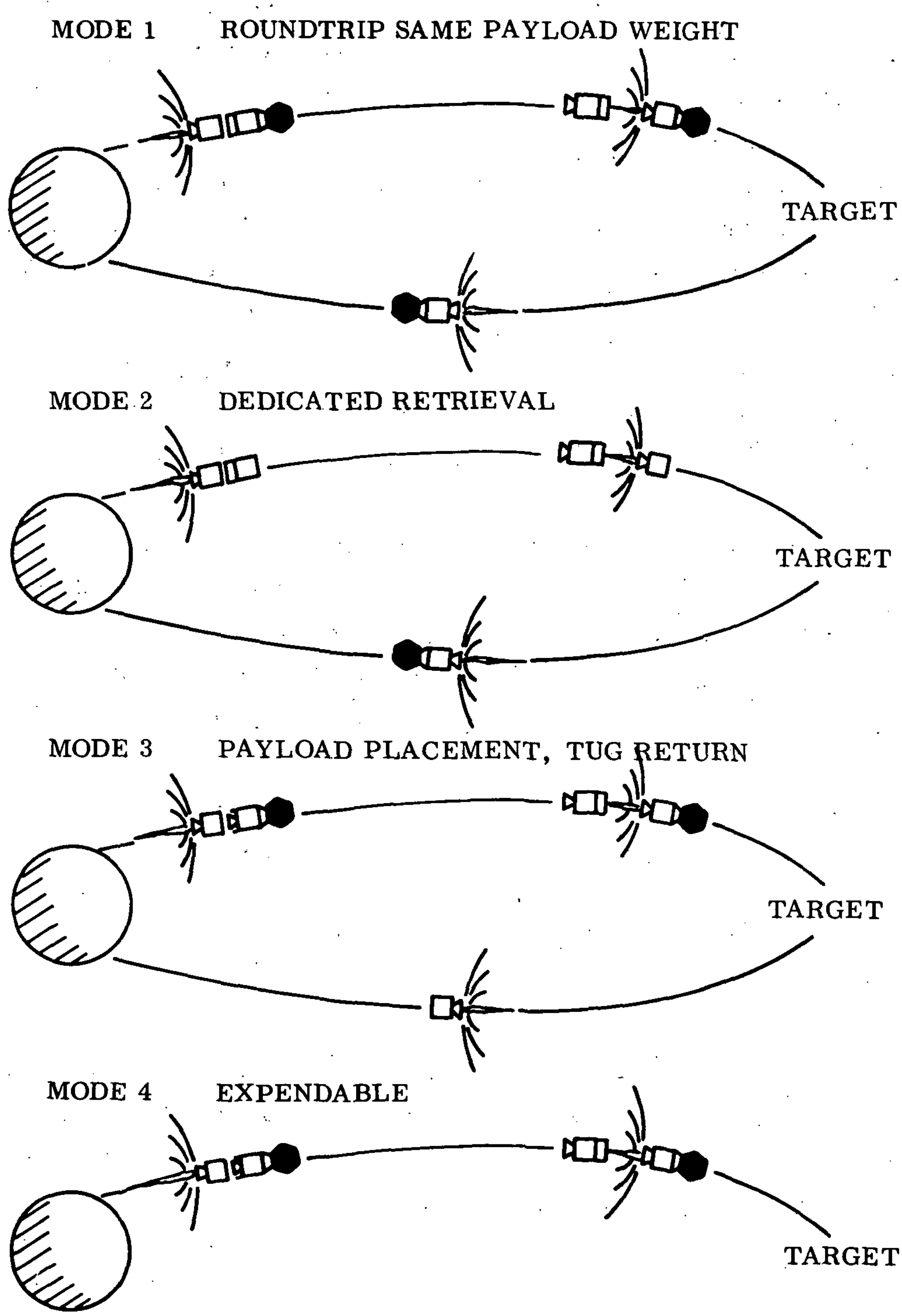


Fig. 9-4 Tandem Agena Space Tug Operating Modes

modes for different types of missions. While the basic performance data are predicated upon an expendable tug operation, payload capability information was also generated for alternative flight modes that reflect recovering the Agena space tug and/or the payload. For all flight modes the first stage is always expended.

Figures 9-5, 9-6, and 9-7 present the payload capability of the three configurations as a function of characteristic velocity and flight modes. The results show that for a one-way expendable flight mode from 100 nm circular parking orbit at 28.5 deg inclination to a synchronous equatorial condition the following payload capabilities can be realized:

Configuration 1	7,000 pounds	(One Shuttle Flight)
Configuration 2	25,000 pounds	(Two Shuttle Flights)
Configuration 3	18,000 pounds	(Two Shuttle Flights)

Placing the large stages in tandem (Configuration 2) also provides the capability to propell a 5000-pound spacecraft on a flyby mission to any of the outer planets up through 1990, or on the grand tour multiple outer planet encounter in the early 1980's. These stages, in conjunction with a retro package providing the required ΔV at planet encounter, also provide realistic payload weights in Jupiter and Saturn orbits.

Figure 9-8 is a comparison of performance capabilities of configurations varying from the single Agena space tug to the evolutionary Agena tandem concept. The comparison is made for Flight Mode 4, expendable one-way flight only, and for UDMH/HDA propellant with 310-second specific impulse in all stages. The gain in performance is impressive.

For the flight modes and configurations described in this section, propellant offloading will occur only for the top stage of Configuration 2 and for certain missions requiring low characteristic velocity. The first stage of this configuration will always be loaded to capacity; it is not affected by the shuttle capability. However, for the second stage there will be a tradeoff between payload weight and propellant weight within the maximum limit of 65,000 pounds. Figure 9-9 shows the optimum propellant loading for the second stage as a function of characteristic velocity and for the four flight modes. Mode 2 is not limited by the 65,000-pound constraint, since this is a retrieval mission and both stages are launched from earth with no payload. The most severe constraint is experienced for the expendable one-way mission, Flight Mode 4.

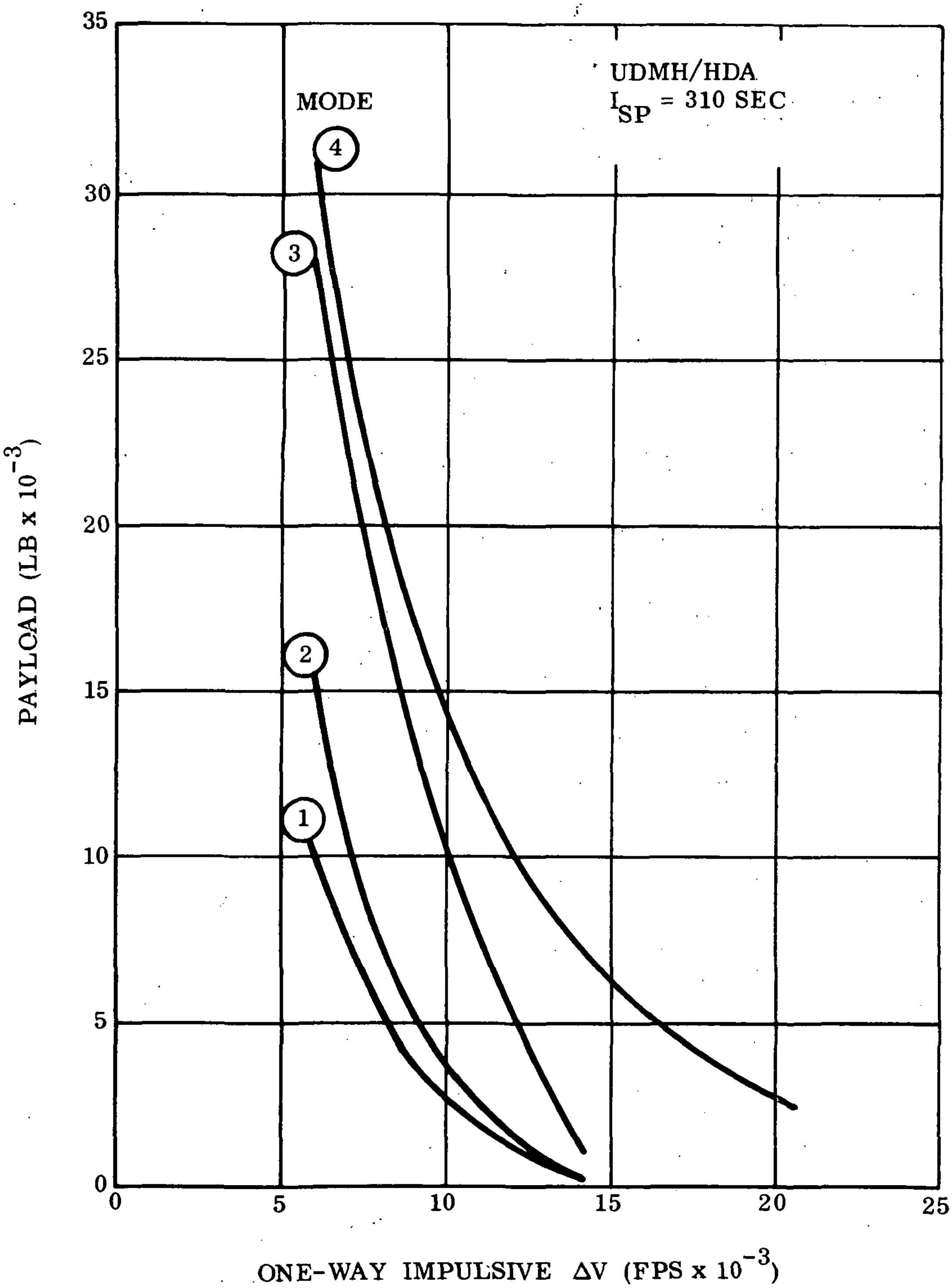


Fig. 9-5 Configuration 1 (5-Ft Tandem Stage) Capability

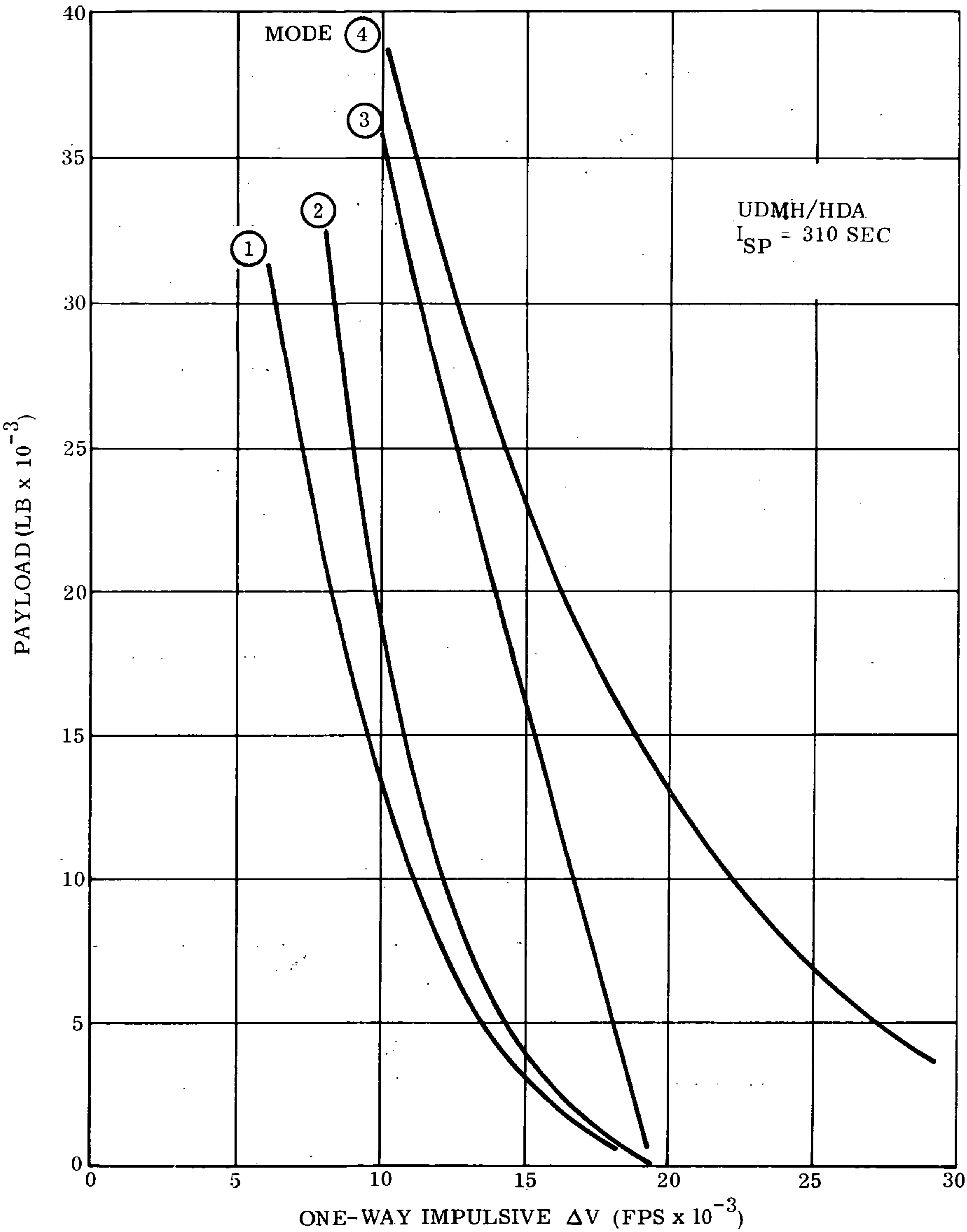


Fig. 9-6 Configuration 2 (10-Ft Tandem Stage) Capability

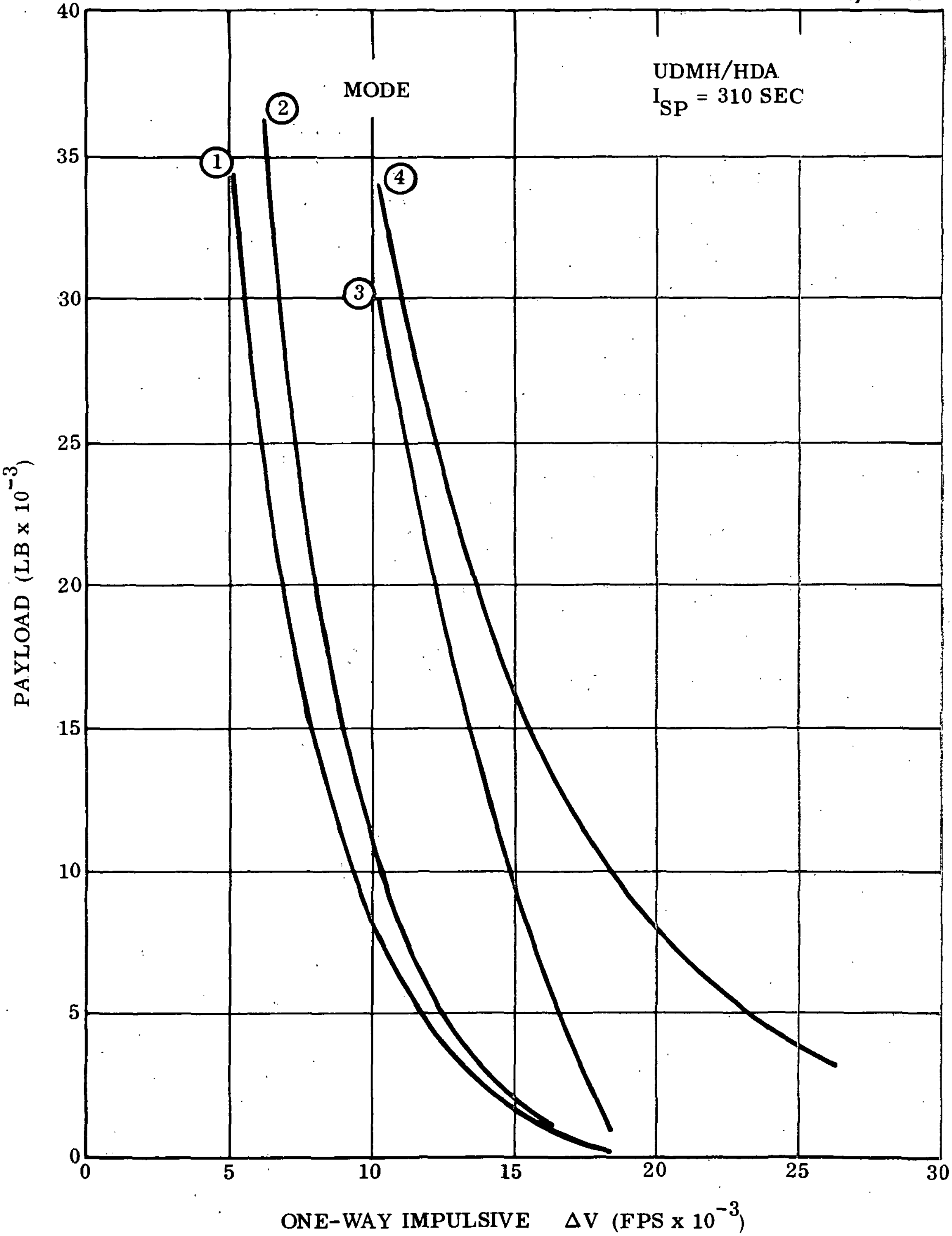


Fig. 9-7 Configuration 3 (10-Ft/5-Ft Tandem Stage) Capability

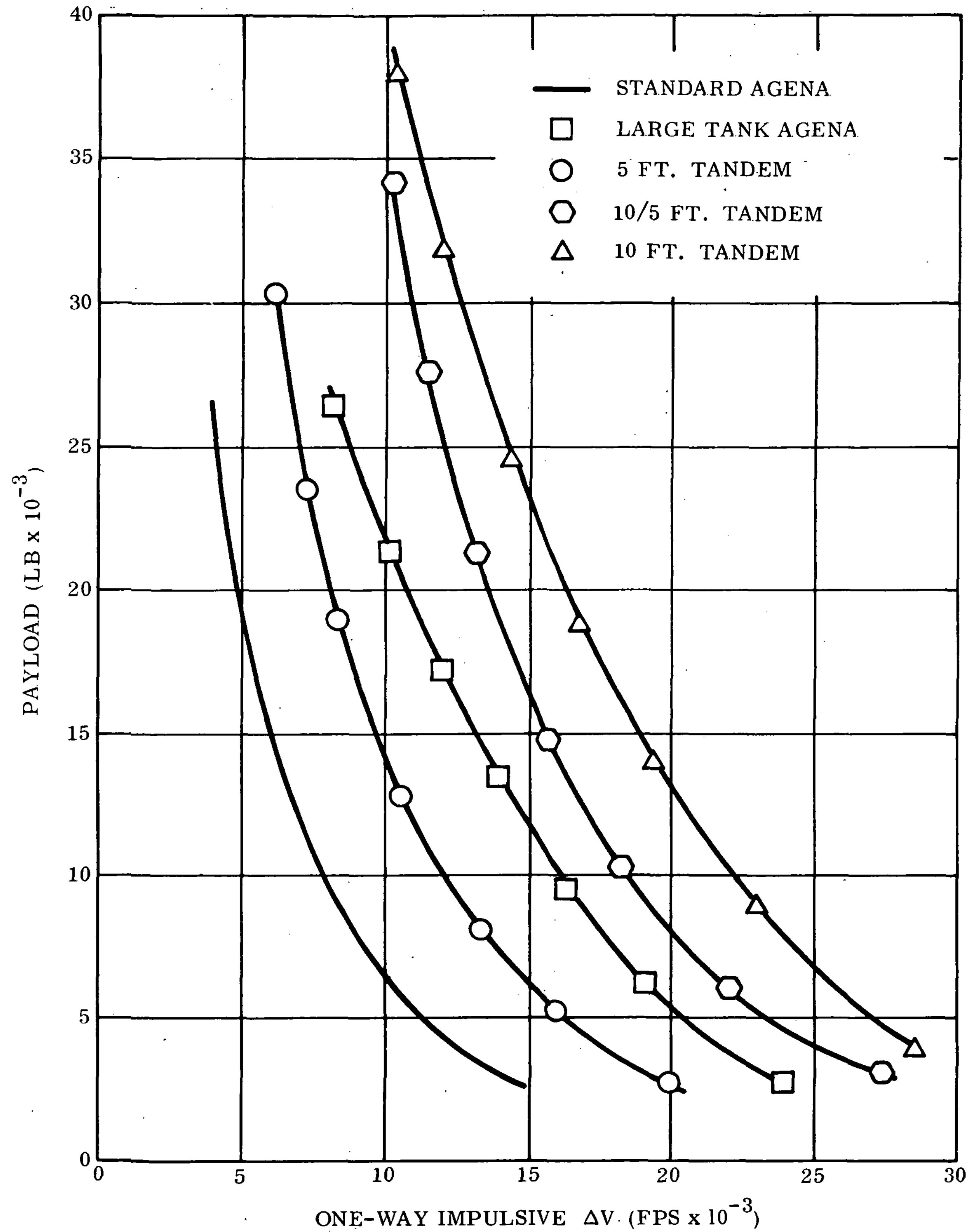


Fig. 9-8 Configuration Performance Comparison for Mode 4

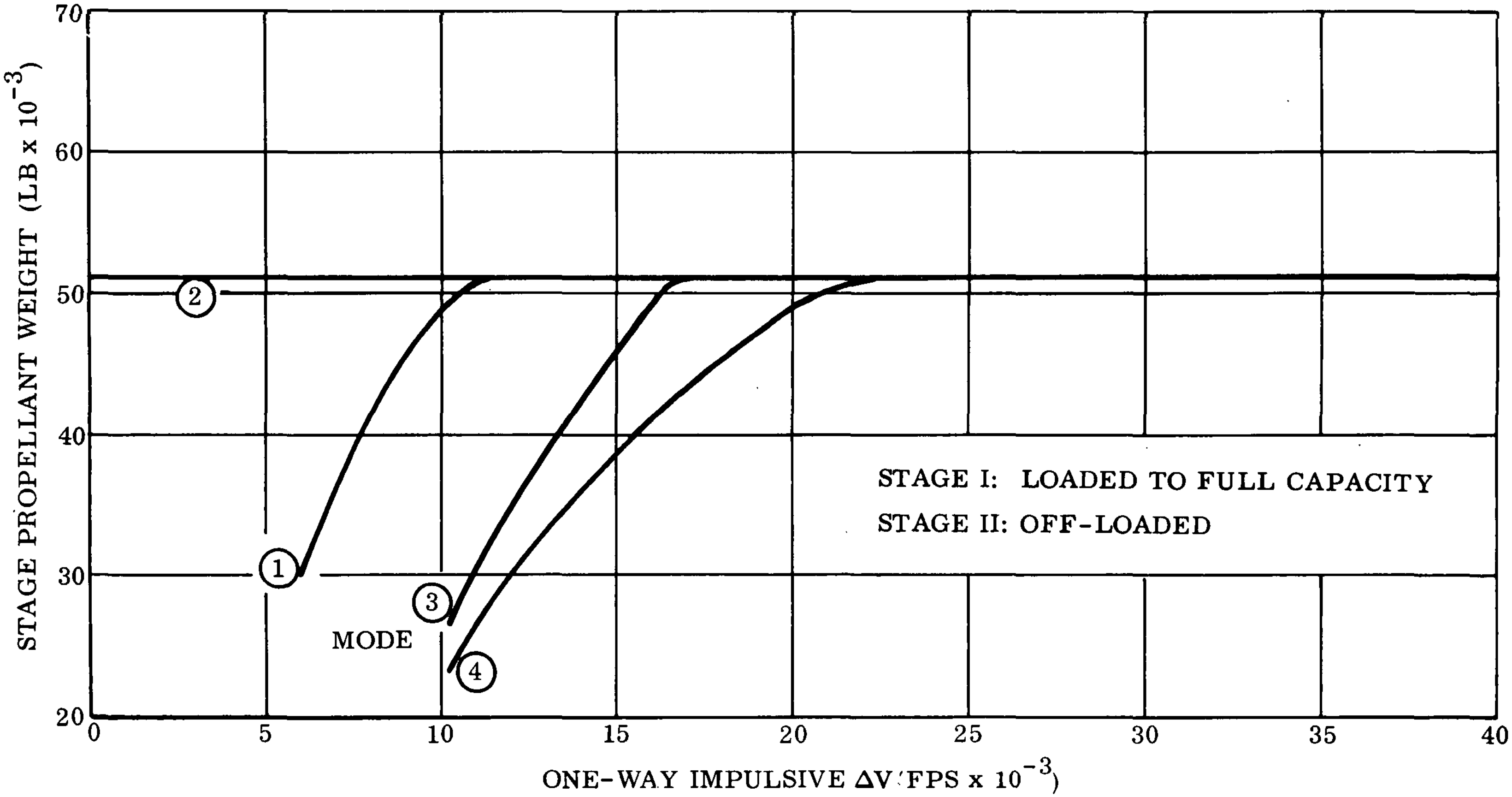


Fig. 9-9 Configuration 2 Propellant Loading

LMSC

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